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VOLUME 17 NOVEMBER, 1943 NUMBER 6

CANINIA FROM THE LOWER CARBONIFEROUS OF NEW MEXICO[1]

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ABSTRACT—Among corals collected from the Lake Valley formation during a stratigraphic and faunal study of the Lower Carboniferous strata of New Mexico by L. R. Laudon and A. L. Bowsher are about 30 specimens that represent a new species of *Caninia*. The new species is described and discussion of the characters of *Caninia* is given.

INTRODUCTION

SPECIES OF *Caninia* (Michelin, 1840, p. 485) are abundant in Carboniferous rocks of Europe and Asia, where many serve as important index fossils, but in America this genus is almost unrecognized. A new species of *Caninia* from the Mississippian strata of New Mexico seems therefore to merit description. The corals here described occur in the lower part of the Alamogordo member of the Lake Valley formation in Lake Valley, New Mexico. Studies by Laudon and Bowsher (1941) have shown that the fossiliferous blue-gray marl facies of the Alamogordo member, containing an abundance of these corals, is developed in the lagoonal areas between the bioherm facies. The simple structure of this species of *Caninia* and its similarity to *C. cornucopiae* Michelin (1840, p. 485) and *C. cornucopiae vesicularis* Salée (1910, p. 24), from the upper Tournaisian of Belgium, suggest correlation of the New Mexico beds with upper Tournaisian strata of Europe.

Sincere thanks are due L. R. Laudon and A. L. Bowsher, of the University of Kansas, for making the corals available for study and to R. C. Moore for aid in the preparation of the manuscript.

DESCRIPTION

Early ideas of *Caninia* were based on *Caninia gigantea* Michelin (1843, p. 81), causing most authors to regard *Caninia* as a junior synonym of *Zaphrenthis* Rafinesque and Clifford (1820, p. 234). The redescription of the genus and correct determination of the genotype as *C. cornicopiae* by Carruthers (1908, p. 158) led to widespread acceptance of *Caninia* as a valid genus.

The genotype is a small coral having few dissepiments and it occurs in the Z and C zones of the Tournaisian, Lower Carboniferous of Tournai, Belgium. A wide range of forms extending from the Lower Carboniferous into the Permian have been referred to *Caninia*, however. Most foreign writers seem to consider these species as grading

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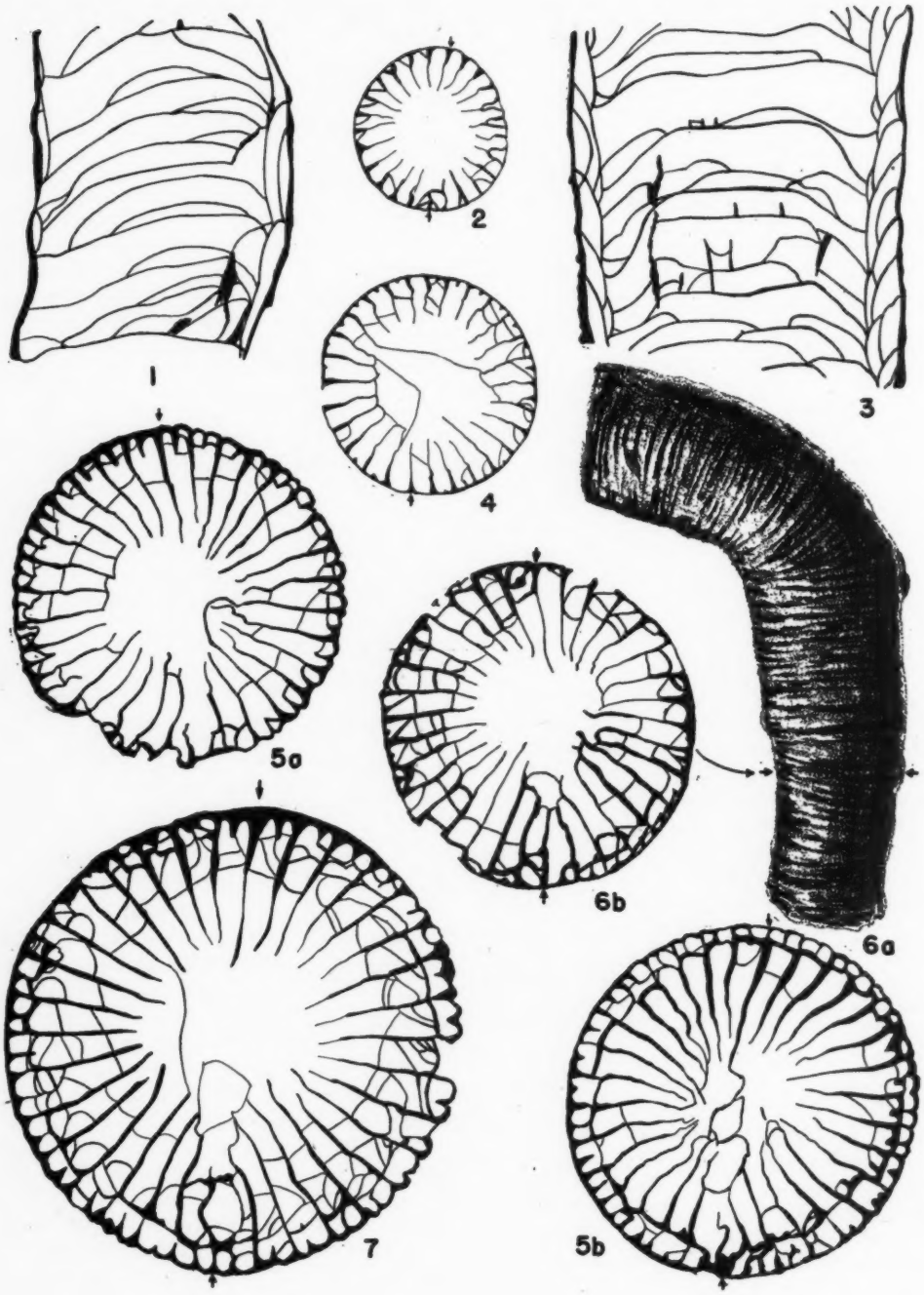

FIGURES 1–7—*Caninia arcuata* Jeffords, n. sp.

into each other and forming a single genetic line. Several new genera have been established to contain some of these differing types, but few authors recognize them.

Siphonophyllia Scouler (1844, p. 187), based on the type species *S. cylindrica* Scouler (1844, p. 187) (= *Caninia gigantea* Michelin), differs from typical *Caninia* in having lonsdaloid septa and a distinct siphonofossula but it is generally placed under *Caninia*. In 1914, O'Connell established the new genus *Siphonophrentis* on *Caryophyllia gigantea* Lesueur (1821, p. 296), which is *Zaphrentis gigantea* of authors. *Siphonophrentis* was intended to include corals having numerous well-developed tabulae and a siphonofossula but lacking an external vesicular zone.

Caninia differs from *Amplexus* Sowerby (1814, p. 165) in the greater length of its major septa, the presence of dissepiments, and in having more numerous tabulae. *Caninophyllum* Lewis (1929, p. 456) differs from *Caninia* in its lack of a breviseptal stage, and the presence of long minor septa and a wide peripheral zone of fine dissepiments.

The similarity of *Caninia* and *Campophyllum* Edwards and Haime (1850, p. lxviii) long has been recognized. Carruthers (1911, p. 149) believed that difference was to be found in the young stages, in which the septa of *Caninia* extend to the center and dissepiments are absent, whereas in *Campophyllum* the septa are short and dissepiments are present. Mature stages seem almost identical in appearance. The type of dissepiments and development of the fossula also have been used to separate the genera.

Relatively few species have been referred to *Campophyllum* in recent years and most authors have considered it a junior synonym of *Caninia*. There seems to be little ground for separation of species referred to *Caninia* and *Campophyllum* and most, if not all, species placed in *Campophyllum* can be assigned properly to *Caninia*—that is, if the present wide concept of the latter genus is accepted.

Hill (1940, p. 116) believes that the type material of *Campophyllum* represents a species of *Palaeosmilia* Edwards and Haime (1848, p. 467). Schindewolf (1941, p. 30), however, considers the type of *Campophyllum* to be a *Caninia*.

The many types of corals referred to *Caninia* and the lack of agreement as to proper generic restrictions indicate the need of further study in order to delineate the several genera properly. *Caninia*, as now defined, comprises solitary corallites of conical to cylindrical form, in which the major septa are long throughout growth but reach the axis only in early stages. The cardinal septum is short and lies in a conspicuous open fossula, but the counter septum may be slightly longer than other septa. Other major septa are approximately equal in length. Minor septa are of various lengths in different species. The acceleration of the counter and cardinal quadrants is

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EXPLANATION OF TEXT FIGURES 1–7

(In each transverse section the counter septum is placed at the top. All figures ×2.5, except as noted.)

Caninia arcuata Jeffords, n. sp. from the Alamogordo member, Lake Valley limestone, Osage series, Mississippian, on Apache Hill, north of Lake Valley, New Mexico.

FIG. *1*—Longitudinal section of a specimen having few dissepiments (Univ. Kansas no. 7955a).

2—Transverse section of a young corallite (Univ. Kansas no. 7955f).

3—Longitudinal section of a mature corallite having numerous dissepiments (Univ. Kansas no. 7955d).

4—Transverse section of an immature corallite having few dissepiments (Univ. Kansas no. 7955g).

5—Transverse sections of a mature specimen (Univ. Kansas no. 7955c). *a*, Section showing short cardinal septum and a narrow band of dissepiments. *b*, Section slightly higher in corallite.

6—Holotype (Univ. Kansas no. 7955b). *a*, Side view showing numerous growth lines and curvature; the marks indicate the position of the transverse section, ×1. *b*, Transverse section showing invaginated tabulae around the cardinal fossula and presence of dissepiments.

7—Transverse section of largest specimen showing short cardinal septum, long counter septum, fossula, and numerous dissepiments (Univ. Kansas no. 7955e).

about equal. Alar pseudofossulae are developed in primitive species. Dissepiments are present at the periphery. Although the genotype has only scattered dissepiments, forms with a broad dissepimental zone are commonly referred to this genus. The complete or slightly inosculating tabulae are broad and convex, the margins being downturned. The tabulae are well developed but variable in regularity. No axial structure is present.

CANINIA ARCUATA Jeffords, n. sp.
Text figures 1–7

?Cyathophyllum subcaespitosum Meek. MILLER, 1881, Cincinnati Soc. Nat. History Jour., vol. 4, p. 308.

This species consists of long cylindrical solitary corallites, most of which are curved or bent. The moderately thick theca bears numerous fine growth lines and low wrinkles but longitudinal markings are absent. The calyx is not well shown in the available material but seems to be moderately deep and to lack any upraised area. Maximum diameters range from 10 mm. to 28.2 mm. The type specimen is 21 mm. in diameter and 95 mm. in length, if measurement is made along the surface of the bent corallite. All the specimens are more or less incomplete.

The long major septa are approximately equal in length and do not reach the axis. The cardinal septum is short, lying in a deep open fossula. Most sections show the counter septum slightly longer than other major septa. Alar septa are not identified. There are 33 major septa in the transverse section of the type specimen and other mature specimens have about the same number. The septa are thin in the young stages but are much thickened peripherally in the later portions of the corallite, where they extend to the periphery through the dissepimental zone. Minor septa are absent in immature stages and short in the mature stage.

The cardinal fossula is large and it persists throughout growth. The downbent tabulae give the appearance of a siphonofossula in transverse section. Dissepiments, lacking in early stages, develop irregularly during later growth. Thus, a definite zone of dissepiments is present only in uppermost parts of the corallites, only scattered dissepiments occurring lower down. More or less complete tabulae, downbent at the margins, regularly cross the interior. Those near the fossula are deeply invaginated around the cardinal fossula.

Discussion.—This species resembles the type of *Caninia* in the irregular distribution of its dissepiments, the short septa of mature stages, and the uparched tabulae. It differs in its larger size, shorter septa of the early parts of the corallite, and downbending of the tabulae around the fossula. *C. arcuta* seems most like *C. cornucopiae* var. *vesicularis* Salée from the Lower Carboniferous limestones of Tournai, Belgium. The two species are alike in their long cylindrical shape and in having few dissepiments, downbent tabulae around the fossula, and short septa at mature stages. The American species is larger and shows greater irregularity in the distribution of dissepiments, wider spaced tabulae, and a more elongate counter septum.

C. arcuta is easily separated from the Upper Carboniferous corals that commonly have been assigned to *Campophyllum torquium* (Owen, 1852, pl. 4), for the latter have a distinct, broad dissepimental zone. I have not seen a detailed description or illustrations of the internal structure of authentic examples of this Pennsylvanian species but corals commonly referred to it should be placed under *Caninia*. It seems probable that study of the type of *Campophyllum torquium* will lead to restricted definition of that species, inasmuch as several different forms evidently are present in material now grouped under this long ranging form.

Occurrence.—Blue-gray marl facies of Alamogordo member, Lake Valley limestone, Osage series, Mississippian (Lower Carboniferous), on Apache Hill, SE. ¼ NW. ¼ sec. 28, T. 18 S., R. 7 W., north of Lake Valley, New Mexico, and Trujillo Canyon, southwest corner SE. ¼ sec. 26, T. 16 S., R. 7 W., about 6 miles southeast of Hillsboro, New Mexico. Collected by L. R. Laudon and A. L. Bowsher.

Material studied.—About 30 somewhat silicified specimens of this species were available for study and a dozen of them were sectioned.

Type.—Univ. Kansas no. 7955b, from Apache Hill, north of Lake Valley, New Mexico.

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TRICERACRINUS, A NEW UPPER PENNSYLVANIAN AND LOWER PERMIAN CRINOID

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ABSTRACT—A new genus and species of inadunate crinoid, named *Triceracrinus moorei*, is described from the lower Permian, of McCulloch County, Texas. It is of special interest because of distinctive characters and narrow stratigraphic range.

INTRODUCTION

DURING recent field investigations of beds referred to the Harpersville formation, in north-central Texas, very distinctive radial and primibrachial plates of a previously undescribed crinoid have been noticed and an unusually well-preserved but incomplete crown and attached portion of the column that reveals all the significant characters has been collected. The ease of recognition and geographic distribution of these plates seem to promise usefulness in future stratigraphic work.

The holotype together with disassociated plates was collected from siltstone only a few inches thick which occurs 10 feet above the "Waldrip No. 3" bed of Drake and 27 feet below the Saddle Creek limestone at a locality in northern McCulloch County, Texas. These beds have been referred to the upper part of the Harpersville formation. According to Sellards (1932, p. 144) this formation is of Pennsylvanian age and occurs well below the base of the Wolfcamp (Permian). He considered the lower boundary of the Permian to coincide with the base of the Moran formation, chiefly because of the occurrence in it of *Pseudoschwagerina* Dunbar and Condra. Cheney (1940, pp. 94–95) proposed to lower the base of the Permian to a horizon below the "Waldrip No. 2" limestone, thus referring the upper part of the Harpersville formation to the Wolfcamp series. Evidence for this change is the occurrence of *Schwagerina* (as emended by Dunbar and Skinner, 1936) in the "Waldrip No. 3" limestone, as reported by Roth (1931).

The thin siltstone, from which the holotype of *Triceracrinus moorei* was collected, can be traced from McCulloch County across Coleman County. It occurs 7 feet above the "Waldrip No. 3" limestone at Roth's locality, 4 miles east of Santa Anna and 1 mile north of the Santa Anna-Brownwood road. I have recently collected *Schubertella kingi* Dunbar and Skinner (identified by Skinner) from a fossiliferous shale 30 feet below the "Waldrip No. 3" limestone at this locality. In this shale there are also numerous free plates of *Triceracrinus*. *Schubertella kingi* is widely distributed elsewhere in lower Permian beds, including strata of the Wolfcamp series in the Glass Mountains of western Texas, the Coleman Junction limestone of north-central Texas, and the Cottonwood limestone of Kansas and Nebraska (Dunbar and Skinner, 1937, p. 611). Thus it seems clear that the beds containing *Triceracrinus* in central Texas should be classed as lower Permian.

In northern Oklahoma and southern Kansas the distinctive primibrachial and radial plates of *Triceracrinus* occur commonly in the Brownville limestone (Moore, personal communication). This limestone is currently classed as topmost Pennsylvanian, the Pennsylvanian-Permian boundary being placed at a prominent disconformity below the Admire group (Moore, 1935, p. 49), which immediately overlies the Brownville. *Schwagerina* is first observed in the northern mid-Continent section at a horizon about 100 feet above the disconformity and *Pseudoschwagerina* occurs 230 feet above this break (Moore and Moss, 1934, p. 100). Therefore information now at hand seems to indicate a slightly earlier appearance of *Triceracrinus* in the northern area.

DESCRIPTION

Genus TRICERACRINUS Bramlette, n. gen.

The dorsal cup is bowl-shaped and moderately low, the sides flaring upward.

The *IBB* are entirely concealed by the stem and lie at the summit of the moderately strong basal concavity. Although not observable, the *IBB* are probably 5 in number as in closely related forms.

The *BB* are bulbous but subangular in outline; they are clearly visible in side view of cup.

The five *RR* have their greatest width along the distal margin. The facets are broad and approximately equal to the width of the *RR*, and they slope outward at an angle of about 20 to 30 degrees. The surface of each *R* is marked by 3 or 4 prominent nodes, which may be erratic in position, or more commonly by only 3 nodes, located at the corners of the subtriangular *RR*.

The PBr_1Br_1 are axillary; their width is greater than their height. They are triangular in shape and slightly narrowed in the middle portion but expand distally to form a prominent node on the lateral margin. The *PBr* projects laterally beyond the *R* and possesses a flat, triangular basal surface, which is bordered laterally by a smooth keel or nodes. The proximal edge is broad and straight; its entire length forms the facet for articulation with the *R*. The facet shows a distinct, straight transverse ridge, a poorly defined outer ligament area containing a centrally located slitlike ligament pit, and a relatively broad inner ligament area that is divided by a shallow intermuscular furrow and sharp intermuscular notch. Two similar but smaller facets occupy the distal surface of the *PBr* for union with the *SBrBr*. Arms are uniserial through at least the third *SBr*; the *SBrBr* are flattened and marked by horizontal keels or nodes.

Three anal plates are present in the cup with one additional anal plate resting on anal *X*. The *RA* rests on the *PB* and the *RPB* and is ornamented with a prominent node; all other anal plates are smooth. Anal *X* rests on *PB* and the proximal margin of *RX* barely cuts the distal surface of the cup.

The stem is round.

Genotype.—*Triceracrinus moorei* Bramlette, n. sp.

Discussion.—*Triceracrinus* closely resembles *Galateacrinus* Moore in several respects. Both possess depressed *IBB* covered by a rounded stem, 5 bulbous *BB*, and three anal plates in the cup. *Triceracrinus* differs in the more deeply bowl-shaped character of the cup, more upwardly directed *RR*, the facets sloping outward, short *PBr* plates projecting outward beyond the *RR*. The shape of the anal plates differs in these genera and the *RX* of *Triceracrinus* occupies a distinctly higher position.

Occurrence.—Upper part of Cisco group, Permian (Wolfcamp) in Texas, and upper part of Virgil series, uppermost Pennsylvanian in Oklahoma and Kansas.

TRICERACRINUS MOOREI
Bramlette, n. sp.
Plate 96, figures 1–15

Dorsal cup is of medium height, truncate bowl-shaped, decidedly angular in outline. The *PBrBr* project outward sharply and overhang the *RR*. In profile the base seems to be subhorizontal but there is a very well marked concavity in the area of stem attachment. The *IB* circlet is small, being covered completely by the stem. The five *BB* are strongly bulbous but not rounded. The proximal parts of the *BB* flare downward but become subhorizontal in their midportion, where they are tangent to the basal plane of the cup. The distal half of the *B* rises vertically, forming a right angle with the basal plane. Lateral portions of these plates are marked by small irregular facets giving irregular rounded nodes and ridges and a subangular outline. The *BB* are subequal, with exception of the *RPB*, which is distinctly larger than the others. The *RR* extend horizontally outward above the *BB* and have essentially vertical lateral surfaces. Viewed laterally, the *RR* have the general outline of an inverted isosceles triangle with an apical angle of about 110 degrees. The three corners are marked by strong nodes; the apical one, much the strongest, has a diameter approximately three times that of the two subequal lateral nodes. The central portion of the *RR*, above the large proximal node, is smooth and slopes gently inward and upward to the outer ligament area. The ligament pit is prominent, horizontal, short, occupying approximately the central third of the

plate. The transverse ridges converge laterally and disappear on the nodes.

Three anal plates are present in the cup and an additional anal plate rests on anal *X*. The arrangement of the anal plates is normal, *RA* touching the *RPB* and *X* resting on the distal portion of *PB*. Only the proximal tip of *RX* is included in the cup and a little more than half of anal *X*. A middle second anal plate, X_2, rests on *X*. The *RA* is bounded by four curved sutures giving a roughly rectangular outline. It differs from the other *XX* in possessing a large, prominent, central node. The remainder of the *XX* are polygonal in outline, flattened, and about equal in size.

The holotype possesses attached *PBrBr* in three of the rays. The PBr_1 is an axillary plate that projects horizontally outward 5 to 6 mm. beyond the subjacent *R*. In general form the *PBrBr* resemble the prow of a ship. The lower surface is flat and triangular in outline with a distinctly keeled margin. The flattened and depressed lateral surfaces meet in a sharp vertical keel that passes into a single prominent node distally. The inner side is occupied by a large facet for articulation with the *RR*. The transverse ridge of this facet is prominent, forming the widest part of the plate, and the ligament pit is deep and short, occupying only about the central third of the width. The central pit, intermuscular furrow, and intermuscular notch are well developed. The upper triangular surface is bisected by a ridge that divides facet surfaces for the two *SBrBr*. The features of these facets reproduce at a smaller scale those already described for the large facet. The *SBrBr* are low and irregular in shape. Like the *RR* and *PBrBr* they possess prominent nodes. These are located at approximately the midheight and in some cases are extended transversely to form short ridges. Two of these nodes are present on all of the *SBrBr*.

The surfaces of all plates are ornamented by numerous fine granules.

The stem is round and has a small circular lumen. The crenellae are prominent. They are about 20 in number and extend halfway to the lumen. The external surface is smooth. Nodal segments are differentiated by slightly larger size from internodals; a single internodal occurs between each pair of nodals.

Measurements of the holotype are: height of dorsal cup, 6 mm.; greatest width of dorsal cup, 16 mm.; diameter of proximal columnal of stem, 3 mm.; height of *BB*, 3–4 mm.; height of *RR*, 4 mm.

Discussion.—*Triceracrinus moorei* can be distinguished from other described crinoids by the triangular, prow-shaped *PBrBr* and subtriangular *RR* ornamented by a prominent node at each of the three corners of the plate. Free *RR* and *PBrBr* plates that have been collected from a shale 30 feet below "Waldrip No. 3" limestone show certain differences in ornamentation from the holotype. The *RR* possess 3 or 4 nodes in erratic positions and the *PBrBr* have a series of nodes on the lateral margins of the basal surface instead of a smooth keel (pl. 69, figs. 8–15). These variations may justify the recognition of a second species when material suitable for description is collected.

Occurrence.—Thin siltstone 27 feet below the Saddle Creek limestone and 10 feet above the "Waldrip No. 3" limestone of Drake, Upper Cisco group, Permian (Wolfcamp); 6 miles northwest of Fife at crossing of Saddle Creek, McCulloch County, Texas.

Types.—Holotype, U. S. National Museum.

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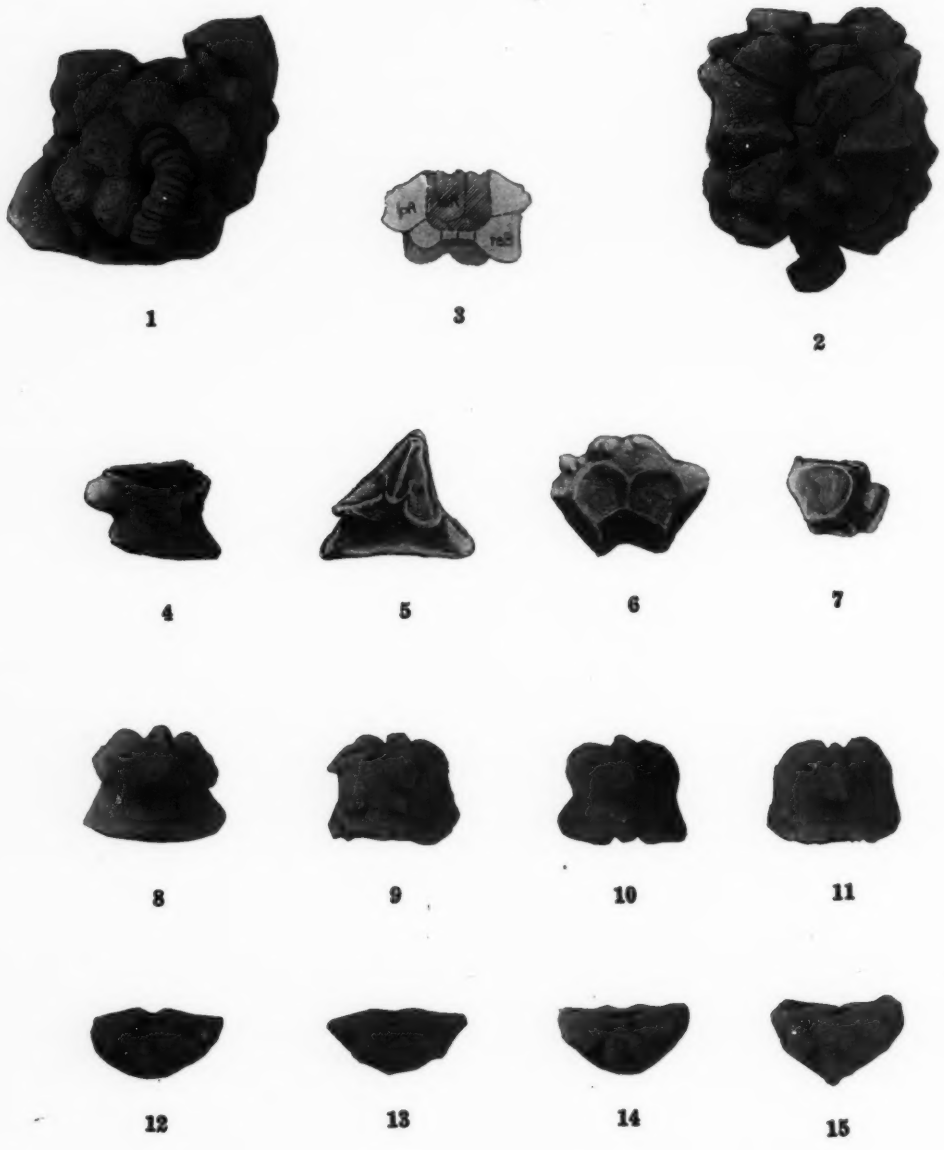

Bramlette, Pennsylvanian and Permian Crinoid

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MANUSCRIPT RECEIVED BY THE EDITOR APRIL 16, 1942.

EXPLANATION OF PLATE 96

Triceracrinus moorei Bramlette, n. gen., n. sp. Holotype ×2

FIGS. *1, 2—1*, Dorsal view; *2*, posterior view.

3—Section through center of left posterior radial and right anterior basal, ×1.3.

4, 5—Camera lucida drawings of separate primibrachial plate from same horizon and locality as holotype, ×2. *4*, side view showing prominent distal node; *5*, top view showing facets.

6, 7—Camera lucida drawing of separate radial plate from same horizon and locality as holotype, ×3. *6*, view from below; *7*, side view.

8, 15—Triceracrinus sp. Front views of separate plates from shale 30 feet below "Waldrip No. 3" limestone, about 4 miles east of Santa Anna, Coleman County, Texas, ×2. *8–11*, primibrachial plates showing variation in ornamentation; *12–15*, radial plates showing variation in ornamentation.

JOURNAL OF PALEONTOLOGY, VOL. 17, NO. 6, PP. 554–583, PL. 97, 13 TEXT FIGS., November, 1943

OPERATIONS OF COMMERCIAL MICROPALEONTOLOGIC LABORATORIES

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ABSTRACT—This article deals with the application of paleontology to the petroleum industry. The aim is to describe the essential operations of commercial laboratories. Emphasis is placed upon methods rather than equipment, by relating what the workers do with a fossiliferous sample after it has been collected and received in a laboratory. The essential work of all laboratories: preparation of material, examination of specimens, analysis of paleontologic data, and interpretation of results is outlined and procedures followed in different types of commercial laboratories are described. Also a representative filing system is explained. Finally, summaries are given of some special techniques that aid routine operations and the presentation of results. An indexed bibliography supplies additional information on several topics which are briefly discussed or omitted because of space limitations.

INTRODUCTION

THIS ARTICLE is one of a series dealing with the application of paleontology to the petroleum industry. Already published are "Applied paleontology" (Schenck, 1940) and "Collecting microfossils" (Schenck and White, 1942). Others that are in preparation will describe micropaleontologic equipment and scientific illustration.

PURPOSE OF LABORATORY

An oil company's paleontologic laboratory exists for the purpose of helping geologists and engineers to interpret stratigraphic and structural conditions and thus aids in the finding of petroleum. Generally, this aid consists of supplying information on the correlation of strata.

The work of a laboratory may be divided into two parts: (1) the preparation of fossils for examination, and (2) the work of the microscopist.

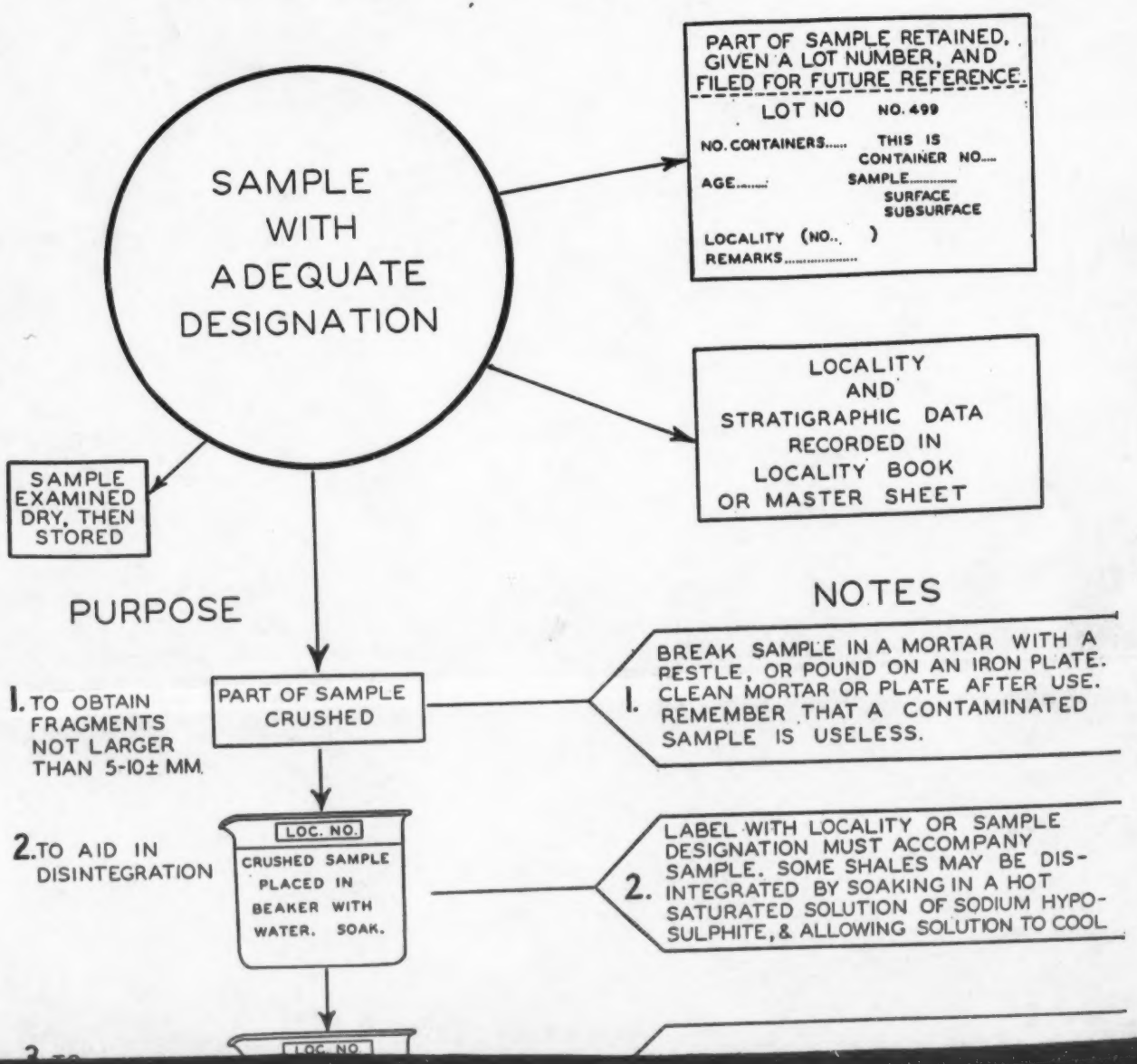
FACTORS GOVERNING PROCEDURE

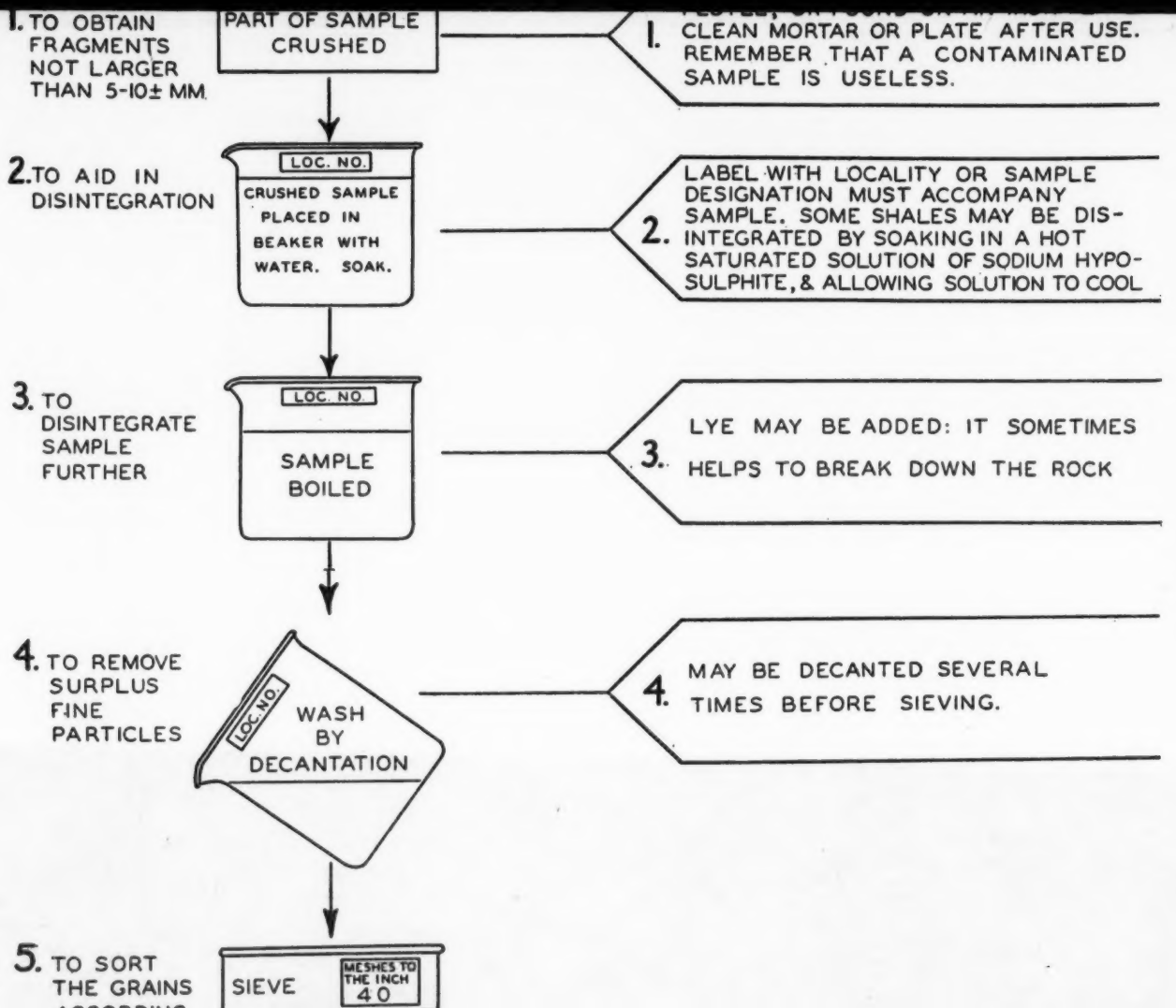
A commercial laboratory must keep abreast of routine assignments, present conclusions in clear form, and build up a store of information. Details of procedure in attaining these objectives vary greatly and all of the phases of technique favored by different micropaleontologists cannot be discussed here.

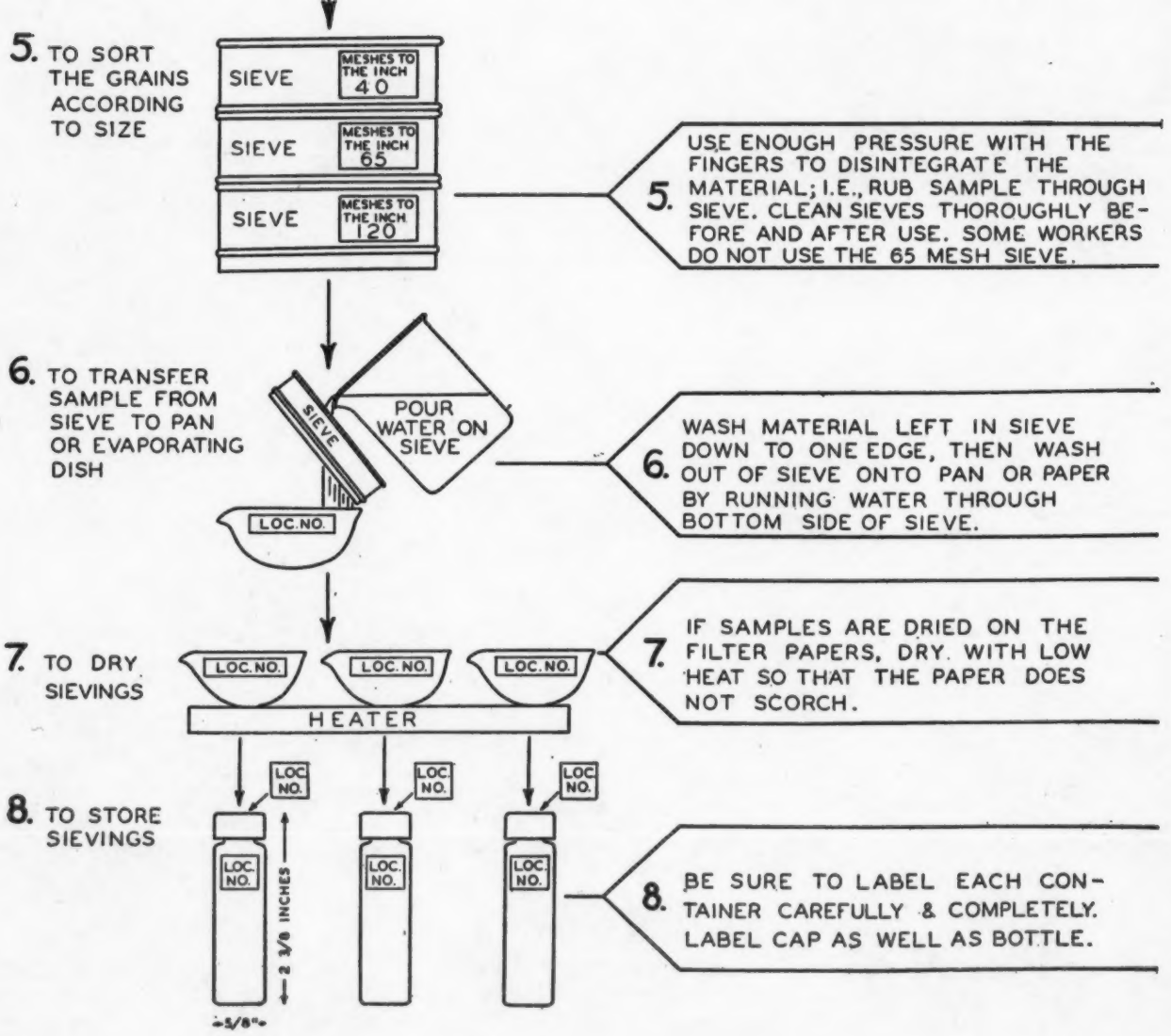
The fact that problems and immediate objectives differ accounts for much of the lack of uniformity in routine laboratory operations. A reconnaissance study, which aims to develop broad problems and to aid generalized mapping over a wide area, requires procedure different from a detailed study of samples from type or "control" sections, either surface or subsurface, for regional work. Also investigations may be concentrated upon a limited area or a single oil field in order to set up detailed local stratigraphic divisions or they may deal with the correlation of certain samples from wells or outcrops in terms of the above operations.

The accomplishments of such studies are limited by many practical requirements. Economic work frequently demands study of a new problem before the one already being investigated is completed. When any group of paleontologists are working together, individual opinions and favored practices must be subordinated to the routine of the organization and rarely do workers have the opportunity to undertake detailed research. The same consideration places emphasis on speed, which is a noteworthy limiting factor. Moreover, different localities present different types of problems, so that a laboratory in one area may adopt certain methods which are un-

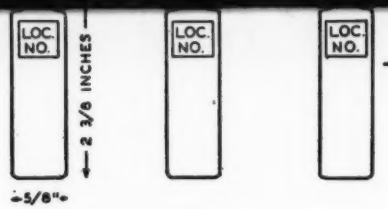
STEPS IN PREPARATION OF CLAY SHALES AND SOFT SILTSTONES FOR EXTRACTION OF MICROFOSSILS, USING SIMPLE EQUIPMENT


SAMPLE WITH ADEQUATE DESIGNATION
PART OF SAMPLE RETAINED, GIVEN A LOT NUMBER, AND FILED FOR FUTURE REFERENCE.
LOT NO NO. 499
NO. CONTAINERS..... THIS IS CONTAINER NO....
AGE.....; SAMPLE.....
SURFACE
SUBSURFACE
LOCALITY (NO..)
REMARKS.....
LOCALITY AND STRATIGRAPHIC DATA RECORDED IN LOCALITY BOOK OR MASTER SHEET
SAMPLE EXAMINED DRY, THEN STORED
PURPOSE
1. TO OBTAIN FRAGMENTS NOT LARGER THAN 5-10± MM.
PART OF SAMPLE CRUSHED
NOTES
1. BREAK SAMPLE IN A MORTAR WITH A PESTLE, OR POUND ON AN IRON PLATE. CLEAN MORTAR OR PLATE AFTER USE. REMEMBER THAT A CONTAMINATED SAMPLE IS USELESS.
2. TO AID IN DISINTEGRATION
LOC. NO.
CRUSHED SAMPLE PLACED IN BEAKER WITH WATER. SOAK.
2. LABEL WITH LOCALITY OR SAMPLE DESIGNATION MUST ACCOMPANY SAMPLE. SOME SHALES MAY BE DISINTEGRATED BY SOAKING IN A HOT SATURATED SOLUTION OF SODIUM HYPOSULPHITE, & ALLOWING SOLUTION TO COOL
LOC. NO


1. TO OBTAIN FRAGMENTS NOT LARGER THAN 5-10± MM.
PART OF SAMPLE CRUSHED
1. CLEAN MORTAR OR PLATE AFTER USE. REMEMBER THAT A CONTAMINATED SAMPLE IS USELESS.
2. TO AID IN DISINTEGRATION
LOC. NO.
CRUSHED SAMPLE PLACED IN BEAKER WITH WATER. SOAK.
2. LABEL WITH LOCALITY OR SAMPLE DESIGNATION MUST ACCOMPANY SAMPLE. SOME SHALES MAY BE DISINTEGRATED BY SOAKING IN A HOT SATURATED SOLUTION OF SODIUM HYPOSULPHITE, & ALLOWING SOLUTION TO COOL
3. TO DISINTEGRATE SAMPLE FURTHER
LOC. NO.
SAMPLE BOILED
3. LYE MAY BE ADDED: IT SOMETIMES HELPS TO BREAK DOWN THE ROCK
4. TO REMOVE SURPLUS FINE PARTICLES
LOC. NO.
WASH BY DECANTATION
4. MAY BE DECANTED SEVERAL TIMES BEFORE SIEVING.
5. TO SORT THE GRAINS
SIEVE
MESHES TO THE INCH
40


5. TO SORT THE GRAINS ACCORDING TO SIZE
SIEVE
MESHES TO THE INCH 40
SIEVE
MESHES TO THE INCH 65
SIEVE
MESHES TO THE INCH 120
5. USE ENOUGH PRESSURE WITH THE FINGERS TO DISINTEGRATE THE MATERIAL; I.E., RUB SAMPLE THROUGH SIEVE. CLEAN SIEVES THOROUGHLY BEFORE AND AFTER USE. SOME WORKERS DO NOT USE THE 65 MESH SIEVE.
6. TO TRANSFER SAMPLE FROM SIEVE TO PAN OR EVAPORATING DISH
SIEVE
POUR WATER ON SIEVE
LOC. NO.
6. WASH MATERIAL LEFT IN SIEVE DOWN TO ONE EDGE, THEN WASH OUT OF SIEVE ONTO PAN OR PAPER BY RUNNING WATER THROUGH BOTTOM SIDE OF SIEVE.
7. TO DRY SIEVINGS
LOC. NO.
LOC. NO.
LOC. NO.
HEATER
7. IF SAMPLES ARE DRIED ON THE FILTER PAPERS, DRY WITH LOW HEAT SO THAT THE PAPER DOES NOT SCORCH.
8. TO STORE SIEVINGS
LOC. NO.
LOC. NO.
LOC. NO.
LOC. NO.
LOC. NO.
LOC. NO.
2 3/8 INCHES
~5/8"~
8. BE SURE TO LABEL EACH CONTAINER CAREFULLY & COMPLETELY. LABEL CAP AS WELL AS BOTTLE.

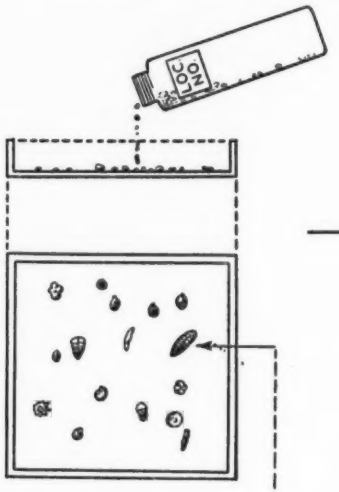
STEPS IN
EXAMINATION AND ANALYSIS



8. BE SURE TO LABEL EACH CONTAINER CAREFULLY & COMPLETELY. LABEL CAP AS WELL AS BOTTLE.

STEPS IN EXAMINATION AND ANALYSIS

9. TO PLACE SIEVED RESIDUE ONE-LAYER THICK ON EXTRACTION TRAY



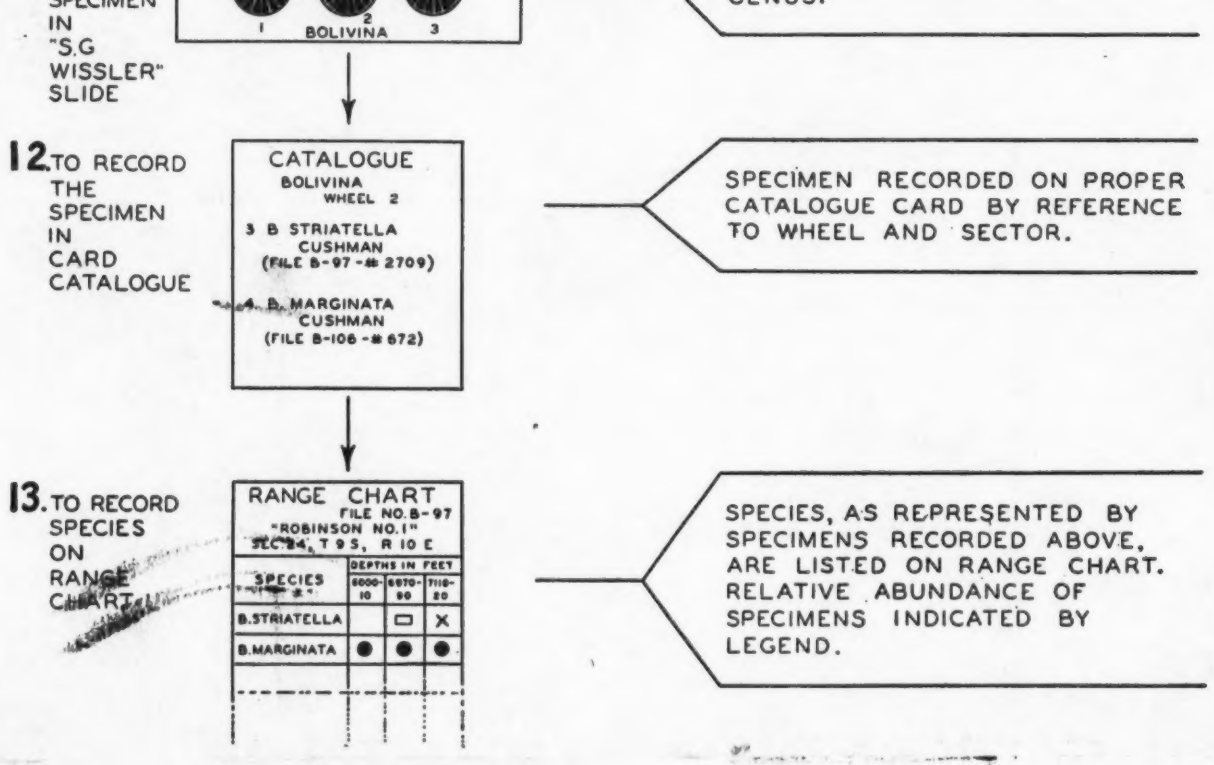
SIEVED MATERIAL SPRINKLED ON EXTRACTION TRAY WITH BLACK SURFACE.

10. TO EXTRACT A SPECIMEN

SPECIMENS REMOVED BY USE OF NEEDLE OR BRUSH. IDENTIFICATION MADE AT THIS STEP.

11. TO MOUNT SPECIMEN IN "S.G WISSLER" SLIDE

SPECIMEN MOUNTED IN SLIDE HOLDING SPECIMENS OF ONE GENUS.



CORRELATION

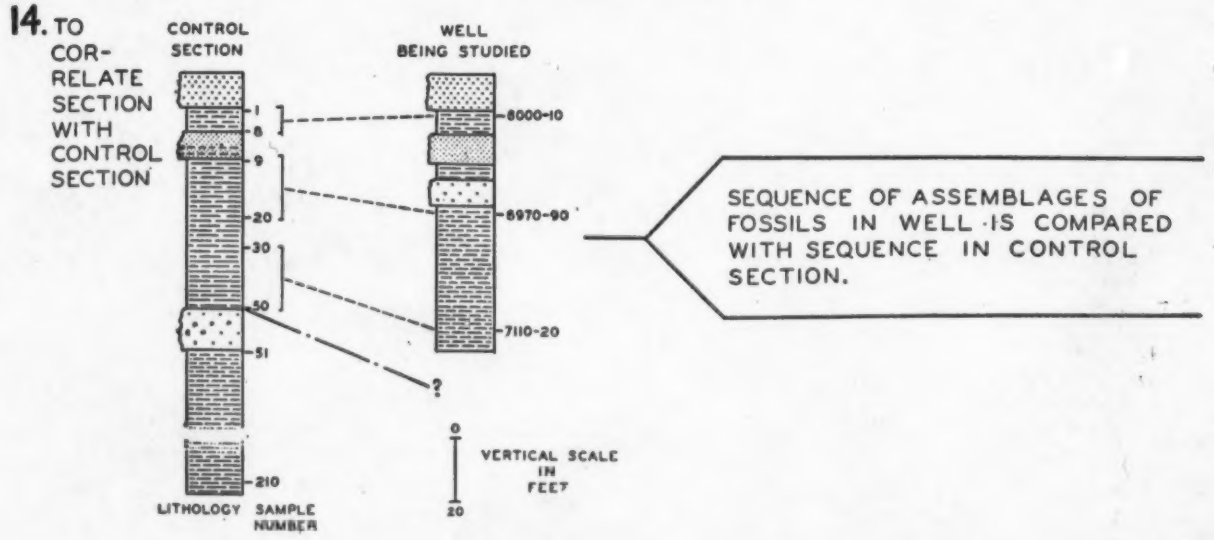


FIG. 1—Essential steps in preparation of clay shale and soft siltstone for extraction of microfossils, using simple equipment; outline of five steps in microscopic examination; and comparison of samples in "control set" with sequence of samples being studied.

necessary in another. Lastly, every laboratory has a limited budget.

PERSONNEL AND BASIC EQUIPMENT

The number of employees in an oil company laboratory may vary from one to about 30. A large representative organization in California consists of a chief paleontologist, two microscopists, four technical assistants, and two technicians. A smaller organization comprises one washman and three microscopists. The staff of a laboratory in Sumatra consists of one senior and two junior paleontologists, two foremen, two technical assistants, and from six to eight sample washers. The work of this personnel is divided between the preparation of samples, their examination under the microscope, the analysis and presentation of results, and the storage and recording of material.

The duties of a chief paleontologist often are largely administrative. He is responsible not only for the smooth functioning of the organization but also for the accuracy of its work. One of his most important duties is to guide the activities in the laboratory along the most practical channels. He also is a microscopist[1] concerned with the examination of prepared samples and he is a stratigrapher who must prepare reports, charts and graphs embodying the geologic results of the investigations.

A technician[2] is a laboratory worker who prepares samples for examination. He has many other duties, such as filing, listing, bookkeeping, and the maintenance of machinery.

The minimum equipment needed by a laboratory consists of beakers and sinks for disintegrating, and sieves for screening samples; apparatus for drying sieved material; a microscope and supplies for the examination of samples; facilities for the preparation of reports and charts; and room and equipment for filing data and storing supplies and samples.

[1] The words "microscopist," "micropaleontologist," and "paleontologist" are used interchangeably in this paper.

[2] The words "technician," "preparator," and "laboratory assistant" are used interchangeably in this paper.

BASIC PROCEDURE

Figure 1 illustrates a skeleton procedure in the extraction of fossils for microscopic study. This process can be used for the preparation of clay shale and soft siltstone, using simple equipment. It commonly is improved upon by the use of specialized equipment and may be modified in order to expedite the preparation of the samples. For instance, rock crushers have such a general use in California that they might be classed as requisite equipment were it not for the fact that the work can be done without this labor-saving apparatus.

The technician first breaks the clean rock sample into small pieces on a clean pounding table or in a mortar (step 1). He places the broken pieces in a beaker or other container and soaks them in water (step 2). If the material is not readily disintegrated, he places a solution of commercial lye (NaOH) in the beaker and adds the dry rock particles to the solution gradually in order to insure proper penetration of the lye. The material is then boiled (step 3) until the fragments have disintegrated. Washing by decantation (step 4) will remove surplus fine particles. The disintegrated residue (step 5) is placed on top of one of a series of two, three, or four sieves of different mesh and washed with water; sometimes the residue may be washed through a single sieve. The sievings on each screen are washed in turn from top to bottom, so that the extremely fine material, such as clay particles, will pass through the finest screen last. Lastly, (steps 6 and 7) the concentrated residue is dried and stored in suitable containers.

A trained preparator never mixes samples and never loses a sample number. Workers use several methods of keeping track of samples during preparation. Some write the number of the sample on the frosted glass of the beaker; some place metal tags in the containers. Technicians who are especially careful to avoid contamination of samples wash the sieves before and after using. Containers, such as jars and beakers, are kept clean and properly labelled. Hammers, pestles, breaking tables, and other equipment, are cleaned after each operation. Even the original sample itself is carefully cleaned of rotary mud or other source of

contamination before preparation is begun. Some laboratories use a blast of compressed air from a hose to clean thoroughly all containers and metal objects.

When the technician has completed the preparation and has bottled and labelled the sample, the work of examination by the microscopist begins.

The microscopist first sprinkles the sievings evenly upon a flat receptacle (step 9) such as a glass dish or "extraction tray." Correctly poured on the tray, all objects are clearly outlined against the dark background. Looking through a binocular microscope, he usually sees clean sand grains and small fossils. The paleontologist will be able to identify many of the fossils without difficulty. Some, however, may be new to his experience or require close comparison with other specimens. Such fossils may be picked up with a moist, finely pointed brush and transferred to the center of a "Stanley G. Wissler[3] slide" (step 10). There he can compare the specimen with others in adjoining sectors and decide on its identification (step 11). For example, the specimen may be identical with those mounted in sector 3 of wheel 2 in his *Bolivina* slide and he will label this specimen "*Bolivina* 203." The first digit is the number of the "wheel"; the second and third digits are the numbers of the sector. Turning to his catalogue, he will find (step 12) that "*Bolivina* 203" has been previously identified as *Bolivina striatella* Cushman.

The paleontologist may find that the specimen is unlike any others he has seen and he will then mount it in a vacant sector, such as number 11 in wheel 3 ("*Bolivina* 311"). He then enters a notation in his catalogue concerning the locality and number of the sample from which the specimen came. Although he may be able to give the specimen a species name, he may prefer a designation by number only.

In this way the paleontologist extracts and identifies a large number of specimens. He records these data on a range chart (step 13). For example, if the sample is recorded as number 6000–10 from file B-97, he will list opposite this number on the range chart the various species and their relative abundance. Other samples from the same well likewise will be studied, as he knows that his data are more reliable if he has a sequence of faunules.

Having made these identifications, the microscopist is ready to attempt a correlation of the strata. To do so he will use a "Control" set (fig. 1, step 14) and endeavor to compare the samples he is studying with this control. For instance, species from the depth 6000–10 feet of the well may be restricted to interval 1 to 8 in the control set; similarly, those from depth 6970–90 feet may be related to samples 9 to 20 in the control; finally sample 7110–20 feet may carry species found only between samples 30 and 50 in the control. He will again look at the lowest samples in the well and see if they have anything in common with the 51 to 210 set of samples in the control. Having found that they do not, he is ready to report to the geologist that the well has not reached the sand found in the control section between samples 50 and 51.

Finally, the microscopist enters this newly gathered information in a suitable file, indexed in such a way that it may be found readily. This particular well now in turn becomes a control section.

ONE-PERSON LABORATORY

A few examples will illustrate how the foregoing outline of operations is modified in practice. One of the simplest commercial laboratories observed by the writers was operated by M.M. Kornfeld[4] in Houston, Texas. This consisted of a moderately sized laboratory and small adjoining office.

After a well sample had been dried in a frying pan on a small gas range it was placed in a coarse screen above a 150 mesh sieve and washed. During washing gentle pressure with the fingers helped to disintegrate the harder shale. After microscopic examination the sieved residues were placed in ordinary paper coin envelopes and stored in cardboard boxes.

If fossils were picked out of the concentrate, they were arranged on slides. As he lacked storage facilities, Kornfeld gave unused material to some interested oil

[3] Union Oil Company, Compton, California.

[4] 1818 Second National Bank Bldg., Houston, Texas.

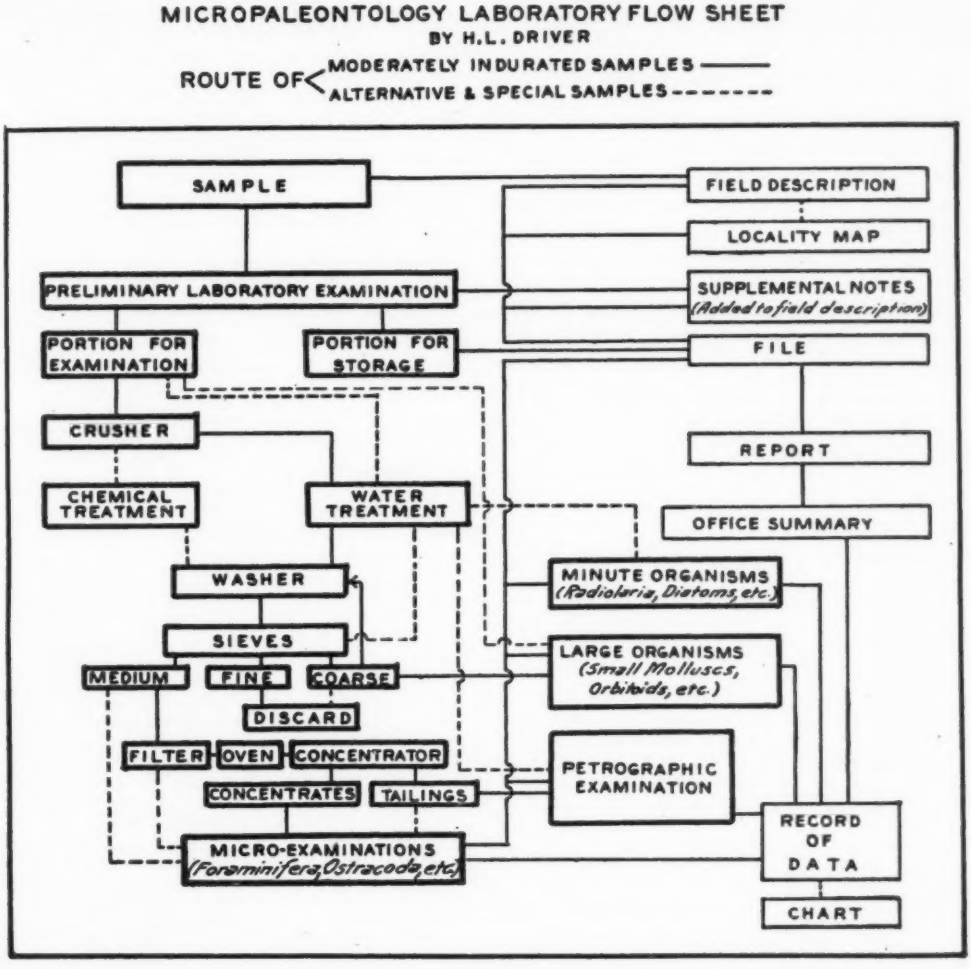


FIG. 2—Flow chart of operations in a medium-sized micropaleontologic laboratory.

company or university so that he might be able to use it again if needed.

For his correlations, this worker made use of lithologic analysis and electric logs, in addition to microfossils. The reader is referred to two papers (Kornfeld, 1930, 1938) which summarize several phases of this technique.

FOUR-PERSON LABORATORY

The chief difference between a one-person and a four-person laboratoy is that the latter is designed to handle more material and consequently has more elaborate equipment. A heavy liquid flotation apparatus can be used to concentrate fossils from certain sandy or silty residues. Additional storage space and cabinets allow the larger laboratory to accumulate material for later reference.

The operations of a medium-sized laboratory have been summarized by Herschel L. Driver[5] (fig. 4).

Moderately indurated foraminiferal samples follow the course indicated by the

[5] Standard Oil Company, Los Angeles, California.

heavy line (fig. 2). Indurated samples proceed from "Portion for examination" to the step marked "Large organisms," where the material is broken into chips and examined under a binocular microscope, or prepared for study by polishing surfaces or making thin sections. Ditch samples follow the route from "Portion for examination" through the "Water treatment," with or without "Washer treatment" into the "Medium" of the sieves, from which the left route leads to examination under water when speed is necessary. The right route from the "Medium" sieve indicates filtering and dry examination. The character of the material, purpose of the examination, and urgency of results, determine the path to be followed by the samples.

Driver makes the following additional explanation of his flow sheet:

> The words "fine," "medium," and "coarse" under "sieves" refer to the texture of the product after it has been sieved. Normally a 20-mesh sieve is nested above a 120-mesh sieve. The coarse product is the material which remains on the 20-mesh sieve. The medium product is the material which passes through the 20-mesh sieve and remains on the 120-mesh one. The fine product is the material which passes through the 120-mesh screen. As indicated on the flow sheet, the fines are discarded. The coarse product may be discarded if it is relatively inorganic and minor in amount; it may be rewashed if an appreciable amount of organic shale is present; or it may be given special examination if fossils such as orbitoids and small molluscs are present. The medium portion is the product examined for small foraminifers. Variation in route on this flow sheet is dependent on the degree of induration of the material and upon the type of fossils to be examined, and not so much on whether the material is from a ditch or core sample.

ROUTINE ANALYSIS OF FORAMINIFERA USED BY THREE LABORATORIES

OBJECT	LABORATORY A	LABORATORY B	LABORATORY C
IDENTIFICATION OF SPECIES	SPECIMENS COMPARED WITH SPECIMENS IN OTHER ASSEMBLAGE SLIDES. NOT NAMED.	SPECIES NAMED BY GENUS AND SPECIES NUMBER AFTER COMPARISON WITH TYPE FILE. PUBLISHED NAME MAY BE ENTERED ON FILE CARD.	SPECIMENS IDENTIFIED TO SPECIES AND NAMED.
PREPARATION FOR ANALYSIS	SPECIFIC COMPOSITION OF FAUNULE AND RELATIVE ABUNDANCE OF SPECIMENS NOTED.	SPECIES AND THEIR RELATIVE ABUNDANCE ARE LISTED ON A "FAUNAL CARD".	A. ALL MATERIAL IS EXAMINED UNDER MICROSCOPE BEFORE BEING WASHED. B. A COMBINED COLUMNAR SECTION-RANGE CHART PREPARED.
COMPARISON	EACH ASSEMBLAGE SLIDE DIRECTLY AND CAREFULLY "MATCHED" WITH OTHER MOUNTED MATERIAL.	A. SPECIES LISTS ON "FAUNAL CARD" COMPARED WITH OTHER FAUNAL CARDS AND WITH RANGE CHART CONTROLLING GIVEN AREA. B. OCCASIONALLY OPERATES LIKE "A".	A. COMPARES THE COMPOSITE CHARTS, ONE AGAINST THE OTHER. B. LOOKS FOR "MATCHES" OF FOSSILS FOR MORE DETAILED CORRELATION.
CORRELATION	A SERIES OF "MATCHES" IN STRATIGRAPHIC SEQUENCE AND RANGE RECORDS CONSTITUTE BASIS OF CORRELATION.	KNOWN RANGE AND DISTRIBUTION OF FOSSILS CONSTITUTE MAIN BASIS OF CORRELATION.	CORRELATION BASED ON LITHOLOGY, RANGE RECORDS OF SPECIES, AND "MATCHES".

FIG. 3—Routine analysis in three California laboratories.

Steps in the microscopic examination and correlation in this laboratory and in two others are summarized in figure 3. In laboratory "B"—the representative medium-size one—the sample is ready for microscopic examination immediately after drying. If a report is urgently needed, the paleontologist may study the wet sample directly after sieving by placing the

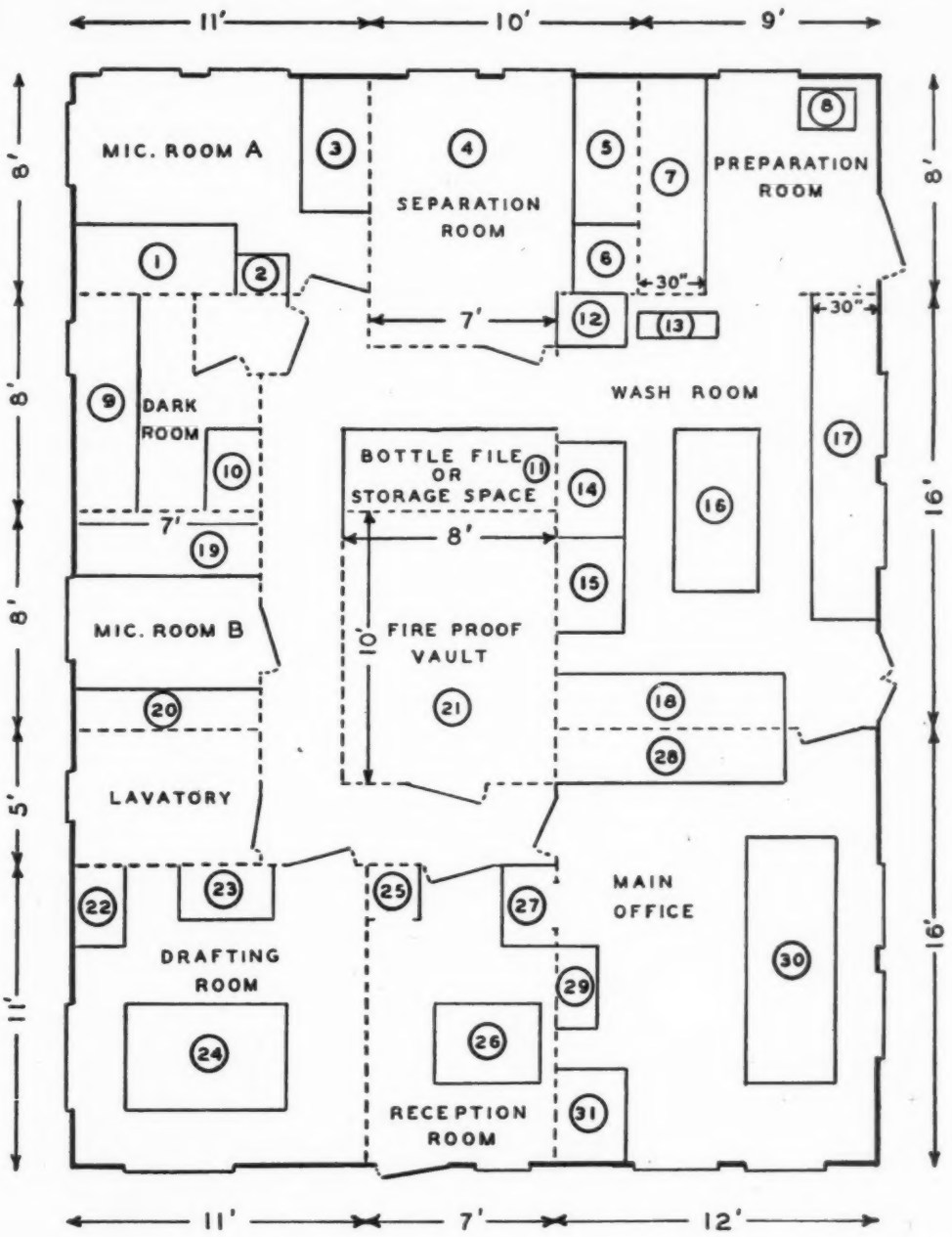


FIG. 4—Plan of hypothetical eight-person laboratory. Sound-proof microscope room "A" equipped with tables (1), (3) and shelf (2). Heavy-liquid separation room contains space for parting liquid equipment, either counter or table (4), counter with cabinet (5), drying oven (6). In preparation room are pounding table (7) and sample crusher (8). Dark room contains counter (9) with sink and cabinet (10) for supplies and equipment. Bottle file (11) provides storage space for prepared material and important slides. Wash room contains drying oven (12), roller (13), sink counters (14), (15), and counters with cabinets (16), (17), shelves with storage space (18). Microscope room "B" equipped with tables and built-in shelves (19), (20). Fireproof vault (21) provides storage for well records, important slides. Drafting room contains tracing table (22), cabinet or shelves (23), and drafting table (24). Reception room with closet (25), desk (26). Main office contains closet (27), shelves (28), bookshelves (29), table (30), and desk (31).

concentrate upon a flat rubber dish and covering the sievings with water.

A worker in "laboratory B" identifies the species by comparison with mounted type specimens. These types are filed alphabetically under the name of the genus, followed by a number which is assigned to each species. A card index to the type specimens carries the specific name of each, if such a name has been determined. The various species in the sample are listed on faunal cards, one card for each sample. The faunal card carries the number or depth of the sample, names of the species, and their relative abundance.

The ranges of the species listed on the faunal card are determined by consulting a master range chart constructed when an area is first studied and kept up to date or modified as information accumulates. A given species may be first reported as appearing within a limited thickness of beds; later work may show that its actual range is greater. Subsequent work may also lead to the conclusion that two or more species had erroneously been listed as one. These changes or modifications are kept before the eyes of the worker by means of the master range chart. Laboratory "B" thus makes correlations by consulting the ranges of the species on an up-to-date range chart. Occasional peculiar or diagnostic faunules are mounted on assemblage slides.

EIGHT-PERSON LABORATORY

Plan.—Figure 4 gives the plan of a hypothetical large laboratory to accommodate eight persons. The samples first go to the preparation room where they are sorted or docketed for the several files. Selected samples are taken to the wash room to be disintegrated and washed through screens. The dried sievings may be concentrated in the separation room. After a final drying, the prepared material is placed in small bottles and stored in the bottle file. The bottled material is examined by the microscopists in well-lighted rooms provided with ample shelf and desk space. The results of the microscopic examination are shown on charts, which are made in the drafting room. The charts are then forwarded to the main office for checking. The main office prepares the final report and passes it on to the proper persons.

A large California laboratory.—Ideal laboratories, such as the one just described, are not built in the economic field, as most organizations must take advantage of available facilities. Such an adaptation is illustrated by plate 97, which shows portions of the Texas Company laboratory.[6]

The sample bags are laid out on a display rack (pl. 97, fig. 1), where they are opened and the contents scrutinized. A "Master sheet" (fig. 5, left column) is made out and the samples listed. After listing and preliminary examination, the technician selects samples for separation. A portion of the contents of each bag is returned to its container which later is stored with others in boxes on the shelves (pl. 97, fig. 1, to the right). The overflow of unused material is kept in a separate warehouse.

The rock sample is broken into small

[6] Furnished by Boris Laiming, The Texas Company, 929 S. Broadway, Los Angeles, California.

EXPLANATION OF PLATE 97

Photographs of The Texas Company Laboratory, Los Angeles, California

FIG. *1*—Preparation room, showing display racks, shelves for storage, wash sinks, and other preparation apparatus.
2—Sinks for washing samples and shelves for holding beakers.
3—Sinks; condenser battery to left.
4—Condenser battery.
5, *6*—Roller mills.
7—Close-up of one of lead-lined sinks.
8—Drier cabinet heated by electric hot-plates.
9—Separation rack.
10—Room for storing bottled concentrates.
11—Microscopist picking and mounting specimens.
12—General view of four large rooms of laboratory.

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Schenck and Adams, Micropaleontologic Laboratory

UNIV. OF MICH.

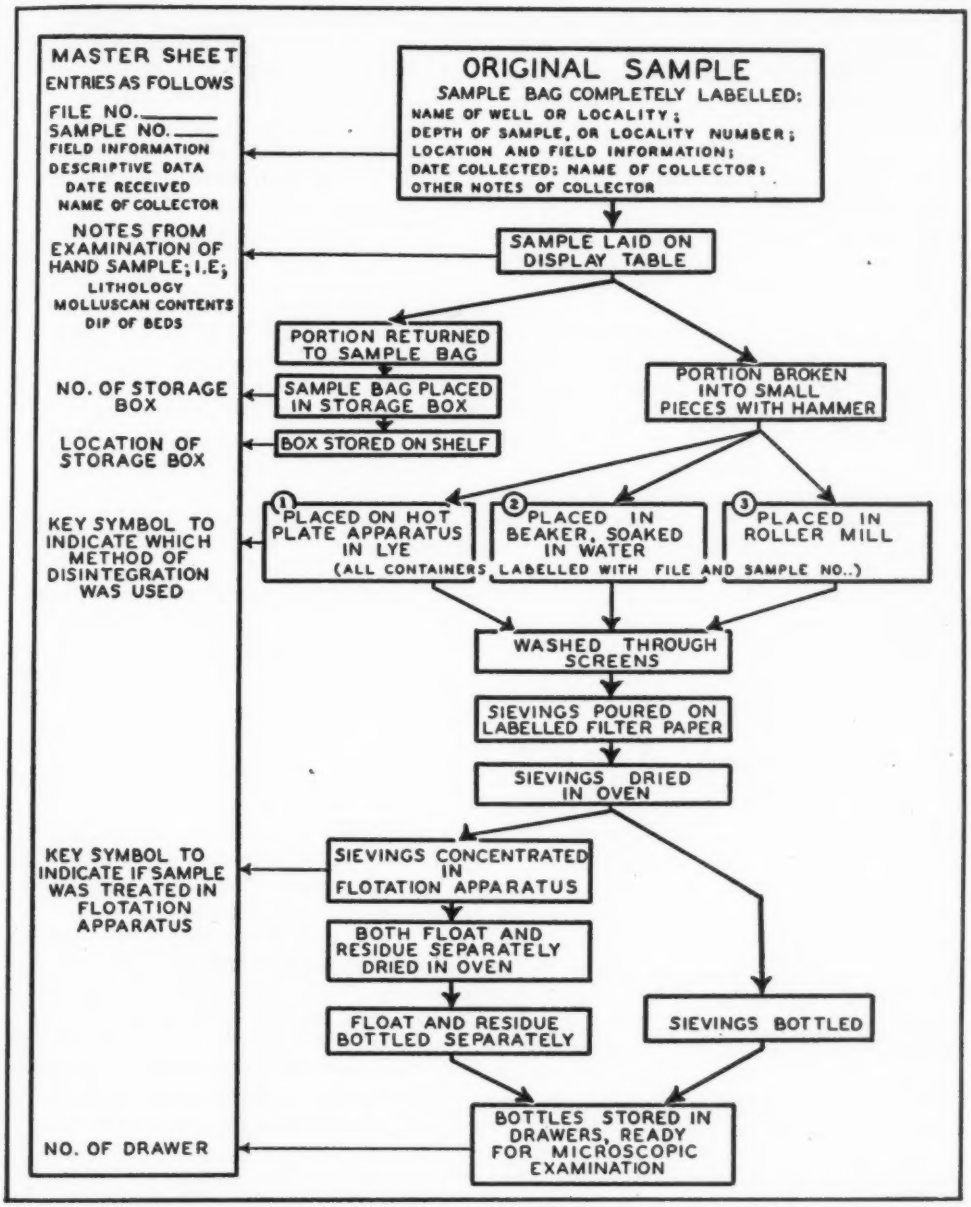

MASTER SHEET
ENTRIES AS FOLLOWS
FILE NO._____
SAMPLE NO._____
FIELD INFORMATION
DESCRIPTIVE DATA
DATE RECEIVED
NAME OF COLLECTOR
NOTES FROM EXAMINATION OF HAND SAMPLE; I.E;
LITHOLOGY
MOLLUSCAN CONTENTS
DIP OF BEDS
NO. OF STORAGE BOX
LOCATION OF STORAGE BOX
KEY SYMBOL TO INDICATE WHICH METHOD OF DISINTEGRATION WAS USED
KEY SYMBOL TO INDICATE IF SAMPLE WAS TREATED IN FLOTATION APPARATUS
NO. OF DRAWER
ORIGINAL SAMPLE
SAMPLE BAG COMPLETELY LABELLED:
NAME OF WELL OR LOCALITY;
DEPTH OF SAMPLE, OR LOCALITY NUMBER;
LOCATION AND FIELD INFORMATION;
DATE COLLECTED; NAME OF COLLECTOR;
OTHER NOTES OF COLLECTOR
SAMPLE LAID ON DISPLAY TABLE
PORTION RETURNED TO SAMPLE BAG
SAMPLE BAG PLACED IN STORAGE BOX
BOX STORED ON SHELF
PORTION BROKEN INTO SMALL PIECES WITH HAMMER
1 PLACED ON HOT PLATE APPARATUS IN LYE
2 PLACED IN BEAKER, SOAKED IN WATER
3 PLACED IN ROLLER MILL
(ALL CONTAINERS LABELLED WITH FILE AND SAMPLE NO..)
WASHED THROUGH SCREENS
SIEVINGS POURED ON LABELLED FILTER PAPER
SIEVINGS DRIED IN OVEN
SIEVINGS CONCENTRATED IN FLOTATION APPARATUS
BOTH FLOAT AND RESIDUE SEPARATELY DRIED IN OVEN
FLOAT AND RESIDUE BOTTLED SEPARATELY
SIEVINGS BOTTLED
BOTTLES STORED IN DRAWERS, READY FOR MICROSCOPIC EXAMINATION

FIG. 5—Flow chart of operations for sample preparation in one eight-person laboratory in California. Brackets and arrows on right indicate various steps and sequence of operations; left column shows how and when entries are made on "Master sheet."

fragments upon a breaking table (pl. 97, fig. 1, in front of sinks). Waste material is brushed through a grill of heavy wire into chutes leading to a receptacle. The fragments are placed either in a jar for rolling or in a beaker, depending on the disinte-

gration technique that is to be followed. The chart (fig. 5) lists three disintegration techniques. Experience and judgment enable the preparator to decide which is most suitable for the individual sample; in practice, the three methods and other improvements are variously combined.

The first method is to boil the sample in lye. This is effective with siliceous or slightly siliceous shales but ineffective for limestones. The well-broken fragments are placed in a beaker of the solution so that the inner parts of the pieces will receive the full strength of the alkali. The beaker is placed on the condenser battery (pl. 97, figs. 2, 3, 4)—an electric hot plate which accommodates 24 300 cc. pyrex beakers. Flasks held by clamps within the mouths of the beakers, connected with tubes, form a water-circulating system. Steam rising from the beaker is condensed when striking the cold surface of the flask and falls back, thus maintaining the solution at proper strength. Boiling is continued until the rock disintegrates. Most technicians refrain from the use of lye whenever possible, as it is a time-consuming method that damages some types of foraminifera.

The second technique, soaking of the rock in water for a short time, is adequate for many types of slightly consolidated rock. In a third technique a roller mill[7] (pl. 97, figs. 5, 6) driven by a ¼-hp. motor is used. Inside each jar a stainless steel roller with ends covered by heavy washers, which partly suspends the roller above the sides of the jar, produces friction sufficient to disintegrate the rock without crushing. Water inside the jar helps in the disintegrating process and acts as a lubricant.

After disintegration, the material is washed through a series of screens, as has been described. Sinks used for this purpose (pl. 97, figs. 2, 3, 97) are lead-lined, ten inches deep, and built to withstand corrosives. Labeled filter paper is placed in one of the funnels on the funnel tray (pl. 97, fig. 7, to the right), and after the residue is washed carefully onto the filter paper, it is taken to the drying cabinet (pl. 97, fig. 8). This oven contains clay crucibles for holding filter paper and residue. After drying, the residue is poured into small bottles labelled on the sides and on the metal caps and stored in drawers (pl. 97, fig. 10) equipped with wire mesh to hold the bottles upright. Some samples if requiring additional concentration are taken to the separation rack (pl. 97, fig. 9) where a gallon bottle of potassium mercuric iodide revolves at the top of a vertical shaft. A tube leads from the bottle to a revolving rack holding separatory funnels. Heavy residues are drained to alternate funnels carrying filter paper on the second rack. After draining, the upper rack is moved over one funnel interval, in order to drain off the light residue. Filtered concentrate[8] and diluted liquid are recovered in alternate beakers on the third or bottom rack.

Other liquids are sometimes used for concentration. Carbon tetrachloride can be used for some material, such as Recent beach sands, or rock that is exceptionally clean and contains well-preserved fossils. The most widely employed solutions are bromoform, ethylene dibromide, and potassium mercuric iodide dissolved in water (Thoulet solution).

Figure 3 outlines the work of a microscopist in laboratory "A" and compares the major steps in the routine analysis followed by three commercial laboratories in California. These, however, are not to be compared in detail because of differences in their sizes, equipment, personnel, and the problems confronting them.

Previous to analysis, one of the paleontologists in laboratory "A" mounts the specimens from a sample upon a single slide known as the assemblage slide. The specimens are mounted alphabetically by genera and relative abundance is indicated by the number of specimens of each species. If there is space, some workers also put a small amount of the concentrate at the bottom of the slide to serve as a sample of the lithology. The assemblage slide is stored in a special cabinet (pl. 97, fig. 12, to right of paleontologist) kept in a fireproof safe.

The paleontologist in laboratory "A" makes a detailed study of the specimens on the assemblage slide but does not name the species.

[7] Invented by E. M. Savage while in the employ of The Shell Oil Co.

[8] "Concentrate" and "residue" are used interchangeably in this paper.

Noting the faunal composition of the slide as a whole, taking into account the relative abundance of specimens of each species, their variations, and other details is the next step. Other assemblage slides from the same well or section are similarly scrutinized. The paleontologist gains, in this way, a composite picture of the distribution of the various faunules in a stratigraphic sequence.

He then tries to match the assemblages upon a chart, which is submitted to the chief paleontologist for checking. The latter thereupon relays the information to the geologic staff. All notes and observations made during the study are preserved for future reference.

SIMPLIFIED ROUTINE ANALYSIS

Figure 3 also summarizes the microscopic work of a third laboratory ("C") operating in California. This laboratory is smaller

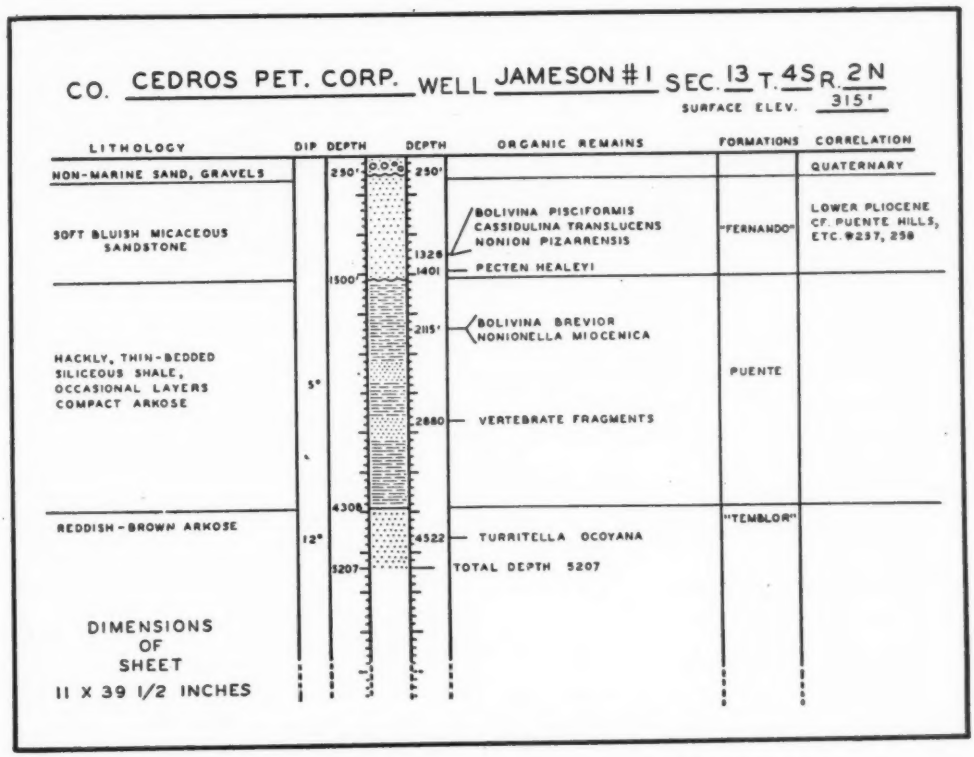


FIG. 6—Log with lithologic notes, columnar section, paleontologic data, and other pertinent information.

with a similar group from a control well or section. Matching is done species by species in all details, and assemblage slide for assemblage slide in nearly all particulars. When a series of matches is found the paleontologist assumes that a thickness of beds are in correlation. This inference is then tested against other evidence, such as lithology.

The results of the work are delineated and lacks the facilities for handling large quantities of material. It therefore applies a more selective process in handling its samples and begins microscopic examination when the samples are first received. At that time fragments of the original material are broken off and examined under the binocular microscope and the paleontologist performs a large part of his lithologic and paleontologic observations. He also selects

a portion of the entire allotment of samples for technical preparation and detailed study. The microscopist prepares a columnar section similar to that depicted in figure 6. On this log he enters the lithologic notes that he made during the preliminary examination, as well as all other data he may have at hand.

Identification of microfossils is accomplished by comparison with a type file, in which specimens are mounted on "Stanley G. Wissler" slides (fig. 7), in a way similar to that outlined under the skeleton procedure.

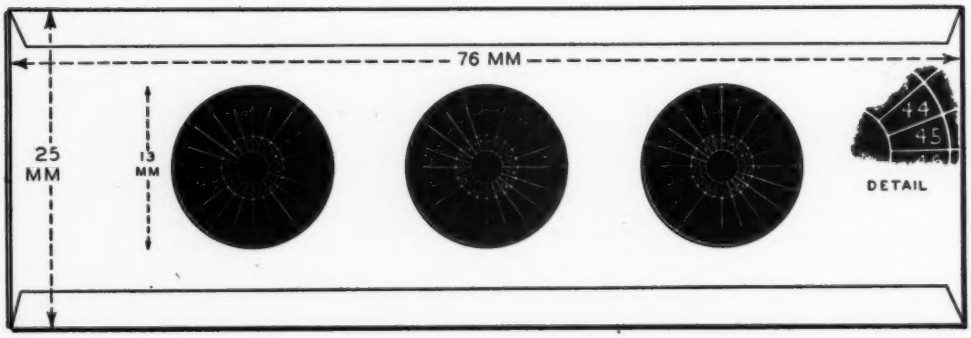


FIG. 7—"Stanley G. Wissler slide." The name of genus is written at bottom of slide and each "wheel" is numbered. The numbers of segments range from 1 to 20 in first wheel, from 21 to 40 in second, and from 41 to 60 in third.

The species and their relative abundance are listed on the composite chart (fig. 6) as shown, or a range graph can be constructed. When the chart is complete, the worker has all his information assembled in convenient, compact form.

The paleontologist compares this composite chart with others, or with whatever controls he wishes to use. When he has an approximate idea of the correlation, he will look for direct matches of assemblage slides as described under the procedure followed in laboratory "A." Correlation is thus based on a comparison of charts, using "matches" for closer detail.

In all three laboratories, the general method of attack follows these steps: identification, analysis, comparison and correlation. Deviations from the procedure occur when certain steps are abbreviated or eliminated. Thus, one worker may not prepare lists nor name species; another avoids preparation of assemblage slides as far as practical; the third tries to conserve both time and effort by working only a fraction of the total number of samples received.

OPERATIONS OF A GULF COAST LABORATORY

The daily work of a Gulf Coast micropaleontologist in one commercial laboratory is summarized by Marcus A. Hanna.[9]

Samples as received from the preparation room consist of original material and washed residues. Notes on the containers indicate whether the cores were free of drilling mud or were contaminated when put to soak prior to washing. The notes indicate also the dips found in the cores and any other pertinent information.

The sample examination consists of two general kinds; (1) routine examination in which well-established zones are determined by paleontologic and lithologic data, and (2) more detailed examination to establish precise zonation. Speed in horizon determination is necessary in routine examination and all that is required is determination of "tops of ranges" of diagnostic species and recognition of distinctive lithologic units. In such an examination of samples, the worker knows approximately where to

[9] Gulf Oil Corporation, Houston, Texas, personal communication.

expect the critical correlation points, because records and maps carry such data. Usually there is a base map on which are posted available subsurface data which are used by the microscopist not only in speeding examination, but also in interpolating gaps, noting changes in thickness of section, and other factors important in deciphering the geologic column.

In routine examination samples are screened and lithologic determinations are made with the binocular microscope. Sometimes thin sections of the rocks are required. "Tops" are picked on the basis of the first appearance of guide fossils, identified by the microscopist whose judgment must be such that checking is not necessary. Slides with mounted or unmounted specimens may not be prepared.

Reports on routine examinations are made usually in summary form. Correlation points based on lithologic characteristics, guide fossils or association of fossils are noted. Generally the faunal zones are not referred to formations because Gulf Coast maps commonly are contoured by zones rather than by formations. The report states whether a guide species first appeared in a core or ditch sample and the sample above the first appearance of a species is noted in order that gaps in the sample sequence will be evident. Detailed reports on the complete sequence are made only when requested, since additional time would be consumed in their preparation.

Detailed examinations are made chiefly on wildcat and other closely sampled wells and in areas where additional precise zonation is needed because of a change in the sedimentary section, deeper drilling, or other reasons. Such an examination requires both lithologic and paleontologic study. Complete assemblages of fossils are prepared and studied, the fossils being placed in individual drawer slides, containing several holes so that both fossils and lithologic samples may be included. Also, the complete sequence of fossils is often mounted on ruled drawer slides for easy access if further study and comparison is required. A search is made for reliable guide fossils, particularly in areas where facies change rapidly. Reports are made in detail on both the lithologic and paleontologic characters of the samples and the materials are filed for future reference.

ROUTINE OF A TROPICAL LABORATORY

The following is a report by Hans E. Thalmann[10] covering the operation of a laboratory at Palembang, Sumatra.

Immediately after receipt, all samples from wells or outcrops are card indexed according to the name of the well or of the geologist. Three-fourths of each sample is prepared for micropaleontologic examination and one-fourth is stored for later reference. Washing is performed by natives under the supervision of a foreman, who also keeps records of the collections and files residues after they have been examined by the microscopist.

A simple procedure for preparing samples was devised after years of experience. The sample is soaked thoroughly, boiled in lye, and screened through standard-mesh sieves under a spray of water and the residues dried on a hot-plate. This method rapidly provides an adequate fossiliferous residue and is generally satisfactory.

The residues are placed in homeopathic vials (as insurance against insects) closed by aluminum screw caps, with cork pad inserts. The name of the well and the depth of the sample, or the number of the field geologist's outcrop, are marked on the bottle cap in india ink. A cursory examination of the contents of the bottles can be made without opening them and major faunal changes can be rapidly noted.

This laboratory could prepare a sample of marl for paleontologic examination within fifteen minutes after receipt and polished sections, oriented either vertically or horizontally, could be made within twenty to thirty minutes. Likewise thin sections could be promptly ground when required.

All work with the binocular microscope was carried on either by Thalmann or by his two assistants. They regarded the faunal associations of a sample as more important for correlation than so-called "markers." Correlation by association required a thorough familiarity with the faunal assemblages of different facies, obtained by

[10] International Petroleum Co., P.O. Box 803, Guayaquil, Ecuador.

the study of type sections. Such sections consisted of cores from wells and uninterrupted series of outcrop samples. Slides made while studying a type section were called "type slides" and carried specimens classified by genera with the different species identified only by numbers (i.e. *Textularia* 3). The species were so thoroughly studied that usually they could be recognized without checking identifications against the types. Thus each worker had to be acquainted with all of the 250 to 300 species of a type collection. New forms discovered during examination of a sample were incorporated in the collection of type slides and given numbers. In this way a type collection was built up for each sedimentary basin (e.g. Northern Sumatra, Central Sumatra, and Southern Sumatra), and the origin of each species was indicated by a prefix. Thus, *Textularia* (NS–1), *Textularia* (CS–1), *Textularia* (SS–1) from the three basins were not necessarily the same species. Identification of specimens with described species was not attempted either during research or routine work. Zones were named after the most conspicuous, frequent, or typical species present in an assemblage that were known to have restricted ranges, i.e. *Textularia* (NS–5) -Zone, *Planulina* (SS–1) -Zone.

From the standpoint of practical stratigraphy it does not matter whether *Textularia* (NS–5), for example, was or was not a true *Textularia mexicana* Cushman. The principal facts established were that this *Textularia* (NS–5) had a restricted range in a particular sedimentary basin, and that there were enough well-preserved specimens in the type slide so that the meaning of the term "*Textularia* (NS–5)" was clear.

Samples from regions newly drilled or explored were studied by the chief paleontologist. A native assisted him in making, numbering, labelling, and storing the type slides. Routine work, on the other hand, was done by a junior paleontologist. When the staff had become familiar with the faunal assemblages of all formations and their different facies in any area, they had only to search for known assemblages of useful "markers."

Collaboration between junior and senior paleontologists was of much benefit. They discussed matters of correlation, changes of facies, faunal peculiarities, and many other problems that daily confront any micropaleontologist. The discussions yielded an enormous amount of information regarding the range and distribution of species, the paleobiologic significance of faunal assemblages, the intercorrelation between sediments and microfauna, and other matters. All these data and all other pertinent stratigraphic information were included in reports to the chief geologist but the naming of species was reduced to a minimum, and voluminous faunal lists were omitted.

The whole staff would at times collaborate in determining the names of species in the type collections. Although this was done principally to satisfy the curiosity of the workers themselves, it helped to sharpen the eyes and minds of the microscopists so that they might recognize subtle differences between species. Thus the workers were forced to keep in touch with current literature, catalogues, and card indices.

The entire faunal content of specially important samples was carefully analyzed. Genera and species were identified by specific number, and new ones were listed and properly stored. Range and distribution charts showing frequency of occurrence were prepared in order to establish the stratigraphic value of each species.

Out of two or three hundred species represented on the type slides, between eight and fifteen percent generally showed restricted vertical range and could be used for direct correlation. These species were labelled "markers" or "guide-forms" and were used for routine purposes. The entire foraminiferal assemblage, however, was studied carefully and with sufficient experience a paleontologist could recognize an important zone even if the so-called "markers" were missing.

The studied material was stored by native assistants, who kept the collections in order. Two of them were also trained to pick out certain species or genera, especially when the paleontologists were rushed. Such work was done by hand more rapidly and efficiently than by any heavy liquid separation. No gum was used for attaching specimens to the slides. So-called "Franke-Hugo Weise slides" were used, in which the speci-

mens could be kept loose and studied from all angles.

Photographs were not prepared in this laboratory, because time was limited and the oil industry is only interested in the application of paleontology to stratigraphic problems. The only illustrations included in the paleontologist's report were columnar sections, correlations between wells, range charts, paleogeographic maps, facies maps, and other charts of value to the chief geologist.

The average number of samples received during a year from wells and outcrops amounted to about 16,000. The average number of samples thoroughly examined and reported upon totalled about 10,000, and the number of memoranda and reports written were about 120 a year.

FILING SYSTEM

Introduction.—All of the work of preparation and study of samples can be lost unless some system is devised to build up and store both the specimens and the information and such storage is an important part of the operations of any laboratory. Numerous systems are used, depending upon the area, the scope of operations of the company, and on the individual preference of the man in charge of the laboratory. Although one method only will be described here, it will serve as an example of a system in use today.

Example.—The basis of the system adopted by one company is geographic. The area of operations is divided into districts whose boundaries are shown on a large wall map and designated alphabetically. A block or drawer in a filing cabinet is reserved for each district and in the front are stored topographic maps covering it. Each filing district is subdivided and data concerning it are placed in legal-sized envelopes. These may consist of the record of a well, an outcrop section, or other data. The subdivision heads are arranged in numerical order, e.g., "B–97" represents head No. 97 in file district B.

The entire file is cross-indexed. A card file, arranged alphabetically by the name of the operator and the name of the well, or by the name of the field geologist and the name of the outcrop, provides a ready reference to any head in the file. Moreover, each file carries a series of facts which are added to as the work progresses. For example, the envelope B–97 contains a lithologic log or other geologic information, an electric log if available, a "master sheet," and miscellaneous information and correspondence.

The "master sheet" (fig. 8) carries the following essential data; name of the oil field or area; names of the operator and well, or names of the field geologist and section sampled; description of location, including section, township, and range; surface elevation and total depth of well; number of slide tray in which mounted slides are stored; total number of samples; date samples were received; number of box in which original samples are stored; depth of each sample or collector's field number, followed by space for abbreviated lithologic, paleontologic, or other notes, and reference to the chart file.

This system is more than a method of filing documents; it is a method of stratigraphic control and it fulfills four important requirements. First, the geographic base is an aid in finding data. Second, flexibility is satisfied, as the system permits expansion. Third, it can be kept up-to-date without the employment of special clerks. Finally, it is systematic.

Figure 9 is a core sample record used by another company in California. Essentially it is the same as the record shown in figure 8, but it carries spaces for other entries required by its special procedure.

SPECIAL TECHNIQUES

Introduction.—Economic paleontologists have developed many special techniques to aid in routine operations. A discussion of these techniques would unduly lengthen this report, but three of them have more than ordinary importance. These are the preparation of assemblage slides, construction of charts, and photomicrography.

Assemblage slides.—Most laboratories reduce the preparation of assemblage slides to a minimum, but all of them find it necessary to make them during the course of their work. Once prepared, such a slide affords an opportunity for a close inspection of specimens—an examination which is not so easily accomplished with loose material.

EXAMPLE OF FILE ("MASTER") SHEET

THE PRODUCING COMPANY
GEOLOGICAL DIVISION
SAMPLE RECORD

FILE NO. B-97

JOHN DOE — OPERATOR
LOCATION 300'N. 600' W SE COR.
SLIDES FILED TRAY 3

ROBINSON NO. 1 — WELL NAME & NUMBER
SEC. 24 T. 9 S R. 10 E
ELEVATION 2000

BLUE GOOSE — FIELD OR AREA
RANGE SAMPLES 6000-8919
NO. OF SAMPLES 3

TOTAL DEPTH 8919 FT.
SAMPLED BY HENRY WALLACE
ORIG. SPLS. IN BOX 24 AT LB

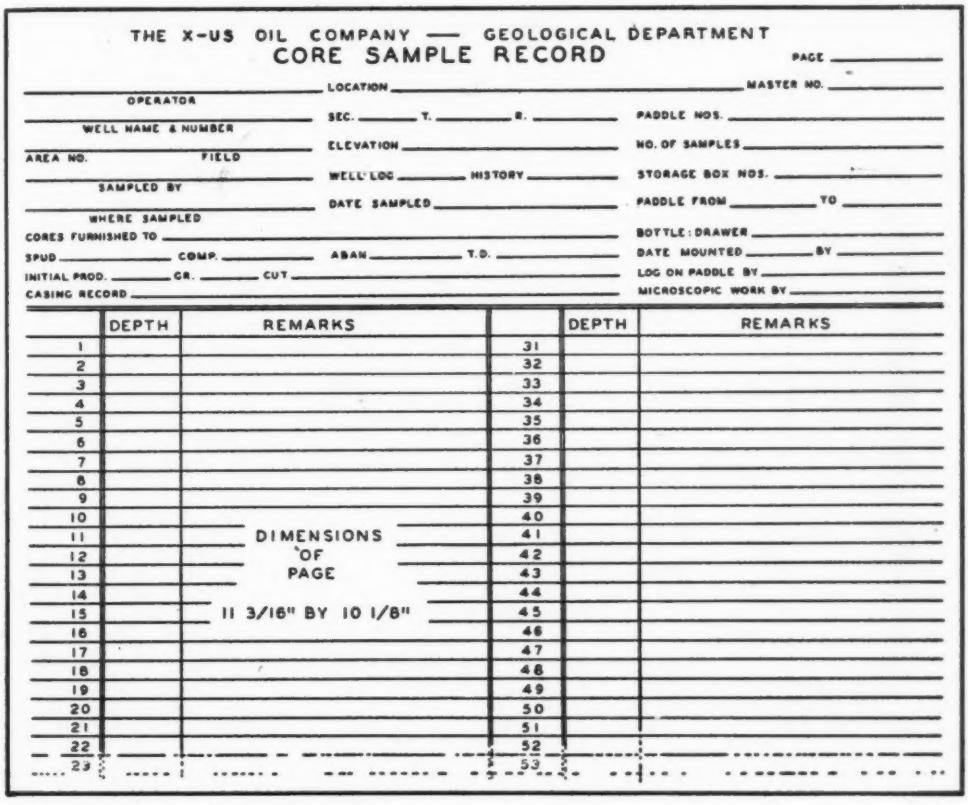
	WHERE STORED		DESCRIPTION OF UNWASHED MATERIAL		
REC'D '41	PREP'D SPLS.	ORIG. SPLS.	DEPTH	LITHOLOGY	REMARKS
5/24	D 4	24	6000 - 10 ‡	BR. SH.	HIGHEST SAMPLE REC'D.
			6970 - 90 ‡	SILTSTONE	
			7110 - 20	GRAY SH.	

NOTES: SHEET IS 8 1/2 INCHES WIDE, 28 INCHES LONG

‡ MEANS WASHED SAMPLE HAS BEEN PICKED FOR FOSSILS

FIG. 8—Example of "master sheet" to accompany records.

The slide must have a large well, or aperture, for holding the fossils, the bottom of which is coated with a solution of gum tragacanth or some similar preparation. The concentrate is placed in an extraction tray so designed (fig. 10) that the level of the tray and slide is the same, and it is not



THE X-US OIL COMPANY — GEOLOGICAL DEPARTMENT

CORE SAMPLE RECORD

PAGE _____

OPERATOR _____ LOCATION _____ MASTER NO. _____

WELL NAME & NUMBER _____ SEC. _____ T. _____ R. _____ PADDLE NOS. _____

AREA NO. _____ FIELD _____ ELEVATION _____ NO. OF SAMPLES _____

SAMPLED BY _____ WELL LOG _____ HISTORY _____ STORAGE BOX NOS. _____

WHERE SAMPLED _____ DATE SAMPLED _____ PADDLE FROM _____ TO _____

CORES FURNISHED TO _____ BOTTLE: DRAWER _____

SPUD _____ COMP. _____ ABAN. _____ T.D. _____ DATE MOUNTED _____ BY _____

INITIAL PROD. _____ GR. _____ CUT _____ LOG ON PADDLE BY _____

CASING RECORD _____ MICROSCOPIC WORK BY _____

	DEPTH	REMARKS		DEPTH	REMARKS
1			31		
2			32		
3			33		
4			34		
5			35		
6			36		
7			37		
8			38		
9			39		
10			40		
11		DIMENSIONS	41		
12		OF	42		
13		PAGE	43		
14			44		
15		11 3/16" BY 10 1/8"	45		
16			46		
17			47		
18			48		
19			49		
20			50		
21			51		
22			52		
23			53		

FIG. 9—Core sample record used by a California company.

necessary to change the focus of the microscope. A slightly moistened brush is used to pick up the fossils and specimens are transferred directly from tray to slide one at a time until a representative number has been obtained. An attempt is made to have every species present in the faunule represented by specimens on the slide. The forms are mounted in neat, regular rows, alphabetically by genera.

The resulting slide (fig. 11) has a series of horizontal rows of microfossils with the representatives of each species arranged systematically by size or variation. For example, one end of a row may show large, spinose forms grading to smaller, relatively smooth individuals at the other. A slide so prepared gives a general idea of the dominant characteristics of a faunule. The number of specimens of each species mounted on the slide serves as a key to their relative abundance.

Chapman (1902) and Helen J. Plummer (1929) have given illustrations of slides for microfossil assemblages which some laboratories use.

Charts.—Figure 12 is an illustration of a greatly simplified range chart. Others may be arranged stratigraphically or biologically. Intricate systems of quantitative analysis are sometimes used (Tromp, 1940). An idea

of the different types of range charts can be obtained by consulting publications by Arnold and Anderson (1910), Beede and Rogers (1908), Dunbar and Skinner (1937), Hecht (1938), and Kleinpell (1938). Most published charts include fewer details than the originals because of necessary reduction for publication.

the many kinds of correlation charts in daily use. A great amount of care and thought go into their preparation because they are the stock-in-trade of most commercial laboratories.

Photographing microfossils.[11]—Good pictures of microscopic opaque objects such as foraminifera can be made photograph-

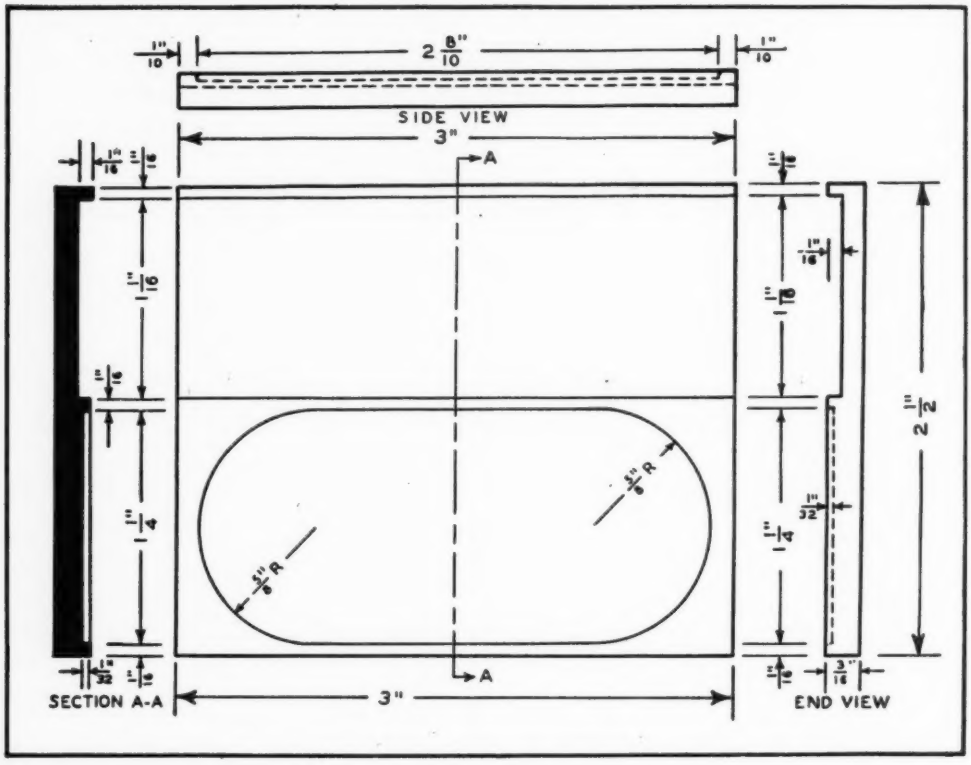


FIG. *10*—Bakelite extraction tray used in the laboratory of Humble Oil & Refining Co., Houston, Texas. This type of tray, but of enamelled wood, was used as early as 1923 by D. D. Hughes in California. Concentrate placed in oval space, slide for fossils quadrangle in same focus.

Figure 13 is an example of a simplified correlation chart. Wells are arranged in sequence as they would occur in a cross section. The wavy lines are taken from electric logs. Correlation lines are drawn on the basis of paleontologic studies and enable closer interpretation of these logs. Generally it is not necessary to list the species; only graphic representation is needed.

Space prevents a detailed treatment of

ically and should be used in preference to drawings, as they are cheaper and more accurate reproductions. Unfortunately, there is no camera on the market which will take satisfactory pictures of opaque, three-dimensional microfossils, and therefore one must be built specially for this purpose.

For a lens holder, use a compound micro-

[11] M. L. Natland, Richfield Oil Corporation, Long Beach, California.

scope frame, with ocular removed, tilted so that the draw tube is horizontal. It should have a revolving stage on which to mount the specimen so rigged that it can be turned by remote control from the ground-glass end of the camera. Often a change of only 3 degrees in the orientation of the specimen, with respect to the lights, will make the difference between a picture which is satisfactory and one which is not. It is not always possible to photograph a specimen with the light coming from the upper left-hand corner although this is desirable. It seems reasonable to sacrifice uniformity of lighting for clearness of detail, if that is necessary.

The resolving power of an objective increases with the numerical aperture or magnification, but as the magnification is increased, there is a loss of depth of focus which is necessary to show three-dimensional objects. Consequently, the rule to follow is: Use the highest-power lens possible which has sufficient depth of focus to show all parts of the specimen clearly. The lenses with 24, 48, and 72 mm. focal lengths

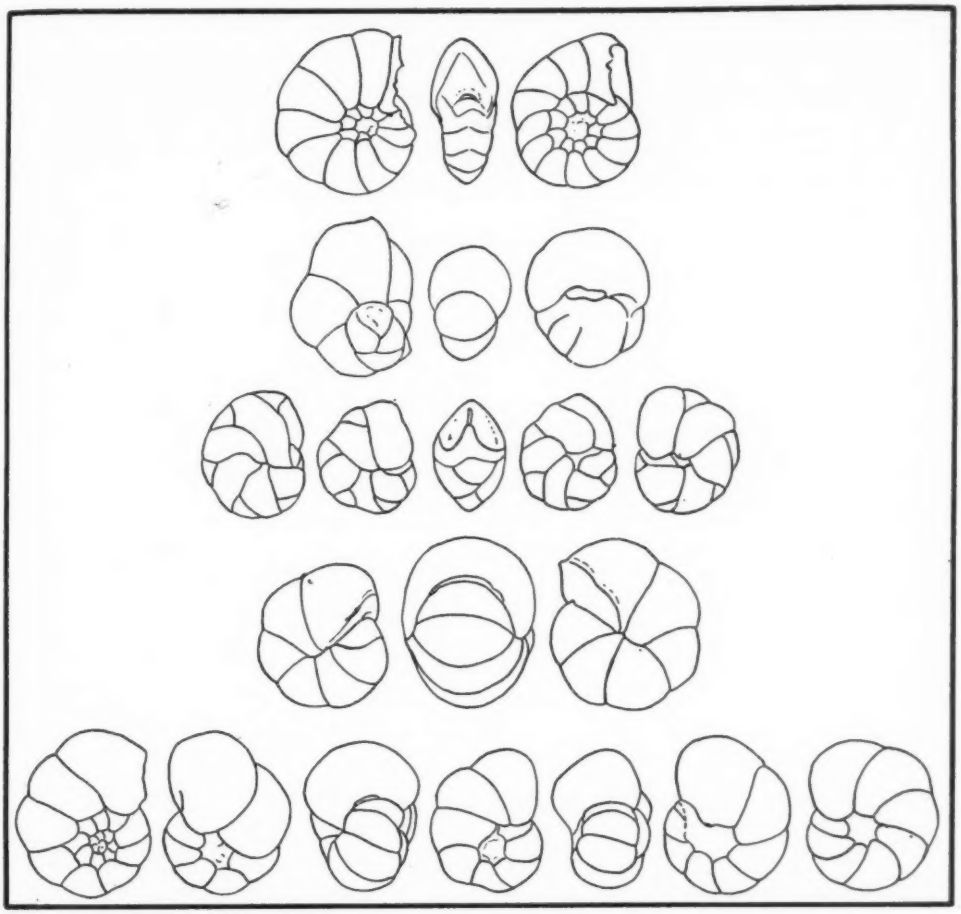


FIG. *11*—Example of simplified assemblage slide. Original slide carried approximately 100 specimens mounted neatly and regularly in 16 rows.

Row 1, *Anomalina* sp. 1; row 2, *Baggina californica* Cushman; row 3, *Cassidulina* cf. *C. pulchella* d'Orbigny; row 4, *Pullenia quinqueloba* Reuss; row 5, *Valvulineria californica* Cushman.

RANGE CHART
(SIMPLIFIED) FILE NO. B-97
JOHN DOE "ROBINSON NO.1", SEC. 24, T 9 S, R 10 E.

SPECIES	DEPTHS IN FEET		
	6000-10	6970-90	7110-20
AMMODISCUS INCERTUS D'ORBIGNY	○	●	○
BAGGINA CALIFORNICA CUSHMAN	○		
BAGGINA ROBUSTA KLEINPELL	●		
BOLIVINA STRIATELLA CUSHMAN		■	X
BOLIVINA MARGINATA CUSHMAN	●	●	●
BULIMINA OVULA D'ORBIGNY	X	X	X
DENTALINA OBLIQUA (LINNE)		■	■
HEMICRISTELLARIA BEALI (CUSHMAN)		●	X
SIPHOGENERINA REEDI (CUSHMAN)		■	
SIPHOGENERINA HUGHESI (CUSHMAN)			■

NOTES

■ = A = ABUNDANT: SO NUMEROUS AS TO DOMINATE THE SLIDE
● = C = COMMON: INTERMEDIATE BETWEEN A AND F
○ = F = FEW: NOT MORE THAN 5 SPECIMENS NOTED
X = R = RARE: NOT MORE THAN 1 OR 2 SPECIMENS

FIG. *12*—Simplified range chart.

are the most satisfactory and they should be stopped down to increase the depth of focus. It is desirable to have a bellows which can be extended from one to six feet.

Proper illumination is very important. Use two 250 watt, 110 volt projection lamps, one at each side of the lens focused to give a strong light. The light should have an angle of incidence of about 10° to the plane of the specimen, to produce shadows that will show its shape. Each light should have a rheostat. Make exposures by snapping the lights on and off. The switches should be mounted on something other than the camera support

as snapping switches and shutters attached to the camera may create vibrations which will blur the picture. Objectionable highlights can be satisfactorily reduced by projecting the image through a polarizer, such as an Eastman Pola-screen Type 1. In order to secure sufficient magnification, the image, generally, must be projected at least two feet. When this length of projection is necessary, a remote control system is convenient, so that the operator, while viewing the image on the ground glass, can operate the focusing screw, rotate the specimen, and vary the intensity of each lamp, in order to obtain the desired image. The exposure should be made on fine-grained panchromatic film, such as Eastman's Panatomic X.

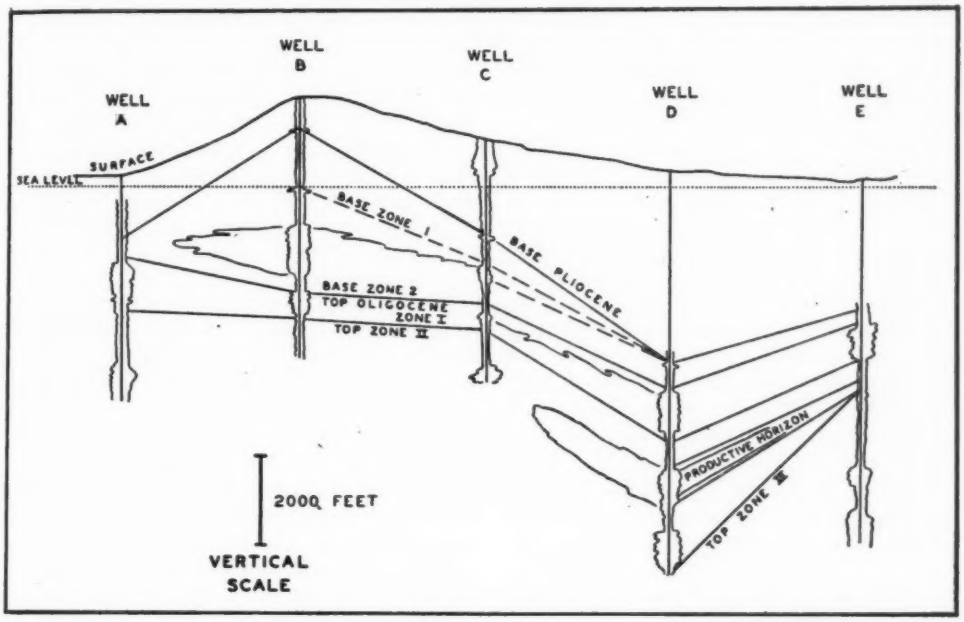


FIG. *13*—Correlation chart based on electric logs of three wells. Correlations indicated by transverse lines.

Thirty-five millimeter film is the most inexpensive to use, but a special camera and focusing apparatus similar to the Speedo-copy camera box holder and ground glass combination are required. This equipment, while expensive, will reduce the cost and time of making exposures to such an extent that it will pay for itself in a short time. The attachment has a hinged ground glass which can be swung over the projected image. When the image is properly focused, the ground glass is swung upward, and the film box, such as a Leica or a Contax box (it must have a focal plane shutter), on another hinge, is swung into a position which coincides with the former position of the ground glass. To make the exposure, turn off the camera lights, open the focal plane shutter, and turn on the lights for the estimated time necessary to expose the film properly. The exposure time varies with each specimen, and must be guaged by the intensity of the light on the ground glass. Close the focal plane shutter, and swing the box down. Then bring the ground glass into position for studying the next image. The developer recommended for the film should be used. It is rather easy to make 75 to 100 pictures daily with the aid of this device.

A simple method of obtaining photomicrographs of thin sections of the larger

Foraminifera was employed by T. S. Childs, Jr., in the micropaleontology laboratory at Stanford University. The section was placed in a good photographic enlarger and used as if the section were a negative. The object was focused at the desired nagnification, blocked out, and a print was made directly from the thin section. The plates in the paper by Schenck and Childs (1942) were prepared by this technique.

The specimens should be measured and, as far as possible, printed so as to show their relative size. Print on paper with a smooth matte finish; do not use glossy paper, as it can not be be retouched. Retouching is not desirable, but, if carefully done, it may improve the pictures, especially those of poorly preserved fossil material.

Print all pictures to the same density by choosing a satisfactory print as a type. Lay it beside the developing tray and match all prints to it. Make the prints a little dark, for, in the half-tone method of reproduction, the picture is lightened somewhat. Mount pictures on flat black cardboard with rubber cement. As a rule, the margins of the specimens on the print will be sharp so that close trimming is possible. Make the plates two or three times publication size, with figures large enough so that the smallest object is not less than one half inch long when reduced to publication size. Do not reduce plates by photostating them, for it will heighten the contrast and much of the detail will be lost.

There are many ways of numbering figures, but perhaps the best is to use a Wrico stencil and pen.

Photographic illustrations of microfaunas are helpful in commercial work. It is often necessary to stop work on one fauna and to start on a totally dissimilar one. In such intermittent work, it is difficult to remember all specific names and much time can be saved by making large plates with the entire fauna illustrated and named.

CONCLUSION

Routine operations of oil company laboratories are much the same in many parts of the world in spite of considerable diversity in the nature of the problems confronting the paleontologists and their differences in viewpoint. Whatever the area and whatever the details of procedure, the operations of these laboratories may be divided into two parts: the preparation of material for examination, and the work of the microscopist in studying and reporting upon the material. Systematic orderliness, fine equipment, and special techniques help speedily to achieve the primary objective—the accurate correlation of strata.

The procedure in a commercial laboratory is not automatic, stereotyped, unthinking mass production of data. It is, on the contrary, research by trained persons who are not only thoroughly familiar with their objectives but also with the difficulties that confront them. Great care must be taken to guard against contamination of samples and no refined techniques, no high-class equipment, nor vast amount of information can offset the lack of intelligence and care on the part of the personnel.

Economic micropaleontologists have contributed little in the way of new techniques. The several methods of disintegrating rock samples have been known for many years; flotation of foraminifers was described by Williamson (1858) nearly a century ago; the value of microfossils for correlation was demonstrated before the discovery of petroleum in commercial quantities; the principles of zonal paleontology were long ago formulated without the benefit of microfossils; the perfection of the microscope cannot be credited to paleontologists. It is true that oil company micropaleontologists have invented some useful equipment but most of it is of minor importance. Principally they have adopted inventions made by others; they have modified equipment already manufactured; they have organized material and personnel for systematic, rapid study. In other ways, however, their contributions have been of great importance: by their refined correlations of strata, they have aided in the discovery of oil and in the unravelling of the complicated history of the Earth.

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The accompanying topical index and alphabetical list of bibliographic references is not exhaustive. Each paper cited has been read by one of the authors of this report; many other papers cited in bibliographies on the Foraminifera have been consulted and found to be irrelevant.

Some of the references deal with special techniques which are not used in all laboratories. Some of them deal with details of procedure that could not be described in this article because of space limitations such as the making of thin sections which ordinarily is not a routine operation in commercial laboratories. Some references to the use of lithology for correlation are included; this is not micropaleontology but paleontologists often find it useful. Included also are several papers dealing with microspores and Recent organisms.

The index is only partly itemized in order to make it as compact as possible. Thus, all disintegration processes are listed under "Smaller Foraminifera" and thin sections under "Larger Foraminifera."

References to many textbooks of paleontology, nomenclators, and other publications useful in identifying and naming microfossils have been omitted. Worthy of particular attention are: Karl A. von Zittel's "Text-book of Paleontology" (English translation, MacMillan Co., vol. 1, 2d Ed., reprinted in 1937); E. Haeckel's "Report on the Rádiolaria" in the Report on the Voyage of H.M.S. "Challenger," vol. 18, 1887; (other groups are likewise treated in these reports); the three volumes on diatom by Mills (1933-34); the list of bryozoan references in Canu and Bassler (1923); the famous monograph by Cayeux (1916) and the bibliography of Foraminifera in Cushman (1940). Emphasis in the following bibliography is placed on techniques other than identification, as systematic bibliographies are already available.

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  - Thin section technique, polished sections, peels (applicable, in part, to rock sections)—Bakx, 1936; Berry, 1931; Camp and Hanna, 1937; Carpenter, 1856, 1862; Chamot and Mason, 1938; Corrington, 1941; Deflandre, 1935; Dunbar

and Condra, 1927; Dunn, 1937; Easton, 1942; Fritz-Gaertner, 1878; Fuller, 1933; Galliher, 1929; Grabau and Shimer, 1910; Hanna, G. D., 1927b; Hanna, M. A., 1927b; Henbest, 1931; Hodson and Hodson, 1926; Hofker, 1930, 1933; Holmes, 1921; Krieger and Bird, 1932; Lacroix, 1935; Leclercq, 1928; Loeblich, 1940; McNair, 1938; Murata, 1935; Murray-Hughes, 1935; Ross, 1924, 1926; Sayles, 1921; Schaffer, 1930; Schneiderhöhn and Ramdohr, 1934; Shaub, 1936; Shrock, 1940; Tolman, 1929; Umbgrove, 1928; Vaughan, 1926; Von Staff, 1910.

Other microfossils.
- Bryozoa—Bassler, 1922; Canu and Bassler, 1923; Foerste, 1887.
- Corals—Easton, 1942.
- Diatoms—Bailey, 1856; Bellido, 1927; Camp and Hanna, 1937; Deflandre, 1936; Francotte, 1883; Hanna, G. D., 1927b; Hanna, G. D. and Grant, 1939, 1940; Keilhack, 1908; Knox, 1942; Mann, 1907, 1922; Mills, 1933–34; Van Heurck, 1896.
- Fossil plants (excluding diatoms).
  - Fossil plants and spores; general references—Camp and Hanna, 1937; Darrah, 1939; Faegri, 1939; Ibrahim, 1933; Knox, 1942; Potonié, 1934; Raistrick and Simpson, 1933; Sahabi, 1937.
  - Sectioning fossil plants—Butler, 1935; Fenton, 1935; Lang, 1926.
- Microscopic teeth—Camp and Hanna, 1937; Eller, 1941; Gumell and Morey, 1932.
- Mollusca and Mollusca fragments—Cayeux, 1916; Creaser and Clench, 1923.
- Ostracoda—Alexander, 1933; Bassler and Kellett, 1934; Brady, 1868; Ulrich and Bassler, 1923.
- Vertebrate remains, fish scales—Camp and Hanna, 1937; Creaser and Clench, 1923; Perruche, 1934.

Lithology.
- General—Boswell, 1933; Bramlette and Bradley, 1940; Graham, 1930; Halbouty, 1936; Milner, 1940; Twenhofel, 1932; Twenhofel and Tyler, 1941.
- Routine preparation and tests—Adams, J. E., 1939; Cayeux, 1916; Claypool and Howard, 1928; Cogen, 1936; Henbest, 1942; Lahee, 1941; Rittenhouse and Bertholf, 1942; St. Clair, 1935; Trager, 1920; Whiteside, 1932.
- Correlation by lithology—Adams, J. E., 1939; Boswell, 1933; Bulman, 1931; Clough, 1936; Cogen, 1936; Dorrell, 1938; Goldman, 1921; Halbouty, 1936; Holmes, 1921; Milner, 1923; Roberts, 1926; Trowbridge and Mortimore, 1925.

Special operations.
- Charts, reports, etc.
  - General—Lahee, 1941.
  - Check lists—Adams, 1943; Arnold and Anderson, 1910; Beede and Rogers, 1908; Hecht, 1938; Kleinpell, 1938; Natland, 1933; Tromp and Izgi, 1942.
  - Correlation charts—Baker, Dane and Reeside, 1936; Gardner, 1927; Hecht, 1938; Kleinpell, 1938.
  - Block diagrams—Lobeck, 1924.
- Illustration.
  - Drawings—Camp and Hanna, 1937; Chamot and Mason, 1938; Cutright, 1930; Hanna, G. D., 1931; Lawrie, 1928; Naylor, 1931; Reeside, 1930; Richards, 1931; Ridgway, 1938; Souèges, 1934.
  - Photomicrography—Bakx, 1936; Barker, 1936; Barnard, 1911; Barnard and Welch, 1925; Burling, 1911; Camp and Hanna, 1937; Chamot and Mason, 1938; Cooper, 1935; Cushman, 1926a; Denne, 1923; Easton, 1942; Grabau and Shimer, 1910; Grove, 1932; Hanna, G. D., 1927a, 1931; Hecht, 1934b, 1935; Henbest, 1934a; Henney and Dubley, 1939; Hervey, 1885; van Heurck, 1893; Hind and Randles, 1913; Kufferath, 1937; Lawrie, 1928; Leclerq, 1933; Loveland, 1943; McNair, 1941; Mehl, 1921; Pringle, 1902; Schneiderhöhn and Ramdohr, 1934; Spitta, 1899, 1920; Van Ingen, 1901; Walmsley, 1902.
  - Use of microscope—Bausch, 1891; Beale, 1880; Beck, 1924; Belling, 1930; Camp and Hanna, 1937; Carpenter, 1883; Chamot and Mason, 1938; Corrington, 1941; Cullison, 1934; Dixon, 1935; Gage, 1917; Goldman, 1925; Hogg, 1861; Lamar, 1929; Lawrie, 1928; Schneiderhöhn and Ramdohr, 1934; Van Heurck, 1893; Winslow, 1905.

General references.
- Routine operations—Barker, 1936; Camp and Hanna, 1937; Chapman, 1902, Cushman, 1925, 1940; Elcock, 1882; Flint, 1886; Franke, 1935b; Hanna, G. D. and Driver, 1924.
- Fossils used for correlation—Barbat, 1930; Barker, 1936; Cartwright, 1929; Davies, 1934–35, 1938; Diener, 1925; Goudkoff, 1926; Kleinpell, 1938; Knox, 1942; Kornfeld, 1930, 1938; Krumbein, 1942; Lull, 1936; Neaverson, 1928; Reed, 1931; Rowe, 1899; Schenck, 1940; Schuchert, 1925; Smith, 1919; Swinnerton, 1923; Williams, 1895, 1901, 1903; Woolnough, 1937.

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EOCENE FORAMINIFERA FROM COWLITZ RIVER LEWIS COUNTY, WASHINGTON

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ABSTRACT—Eocene Foraminifera from Cowlitz River, Washington, are described and figured. The collection of 65 samples from 200 feet of strata contained 107 species and subspecies. Twenty-five species and 8 subspecies are new. The assemblage constitutes but one faunule, which is referred to in introducing the term *Saracenaria mackini* zonule for the strata investigated. An ecologic analysis of the faunule indicates that it possibly lived off a tropical coast in warm marine waters at the outer margin of the neritic zone, down to and perhaps into the upper bathyal zone. The Cowlitz River beds are Eocene; they are in part correlative with the Coaledo formation of Oregon, and the Tejon and Poway formations of California. The Cook Mountain formation of the Gulf Coast contains several species in common with the Cowlitz.

INTRODUCTION

APPROXIMATELY 200 feet of Eocene beds are exposed one and one-half miles east of Vader, Lewis County, Washington, along the west bank of Cowlitz River in E½ SE¼ sec. 28, T. 11 N., R. 2 W., Lat. 46°25′N.; Long. 123° 56′W. Weaver (1912, p. 13) proposed the name Cowlitz formation for the beds containing a molluscan fauna at this locality. Later he (1937, p. 94) expanded the type Cowlitz formation to include strata exposed along Olequa Creek between the towns of Winlock and Vader. This emendation is undesirable because the Olequa Creek section was not included in the original definition and the addition would necessitate two type localities for the Cowlitz formation. The writer limits the type Cowlitz to the beds exposed on Cowlitz River.

G. Dallas Hanna and Marcus A. Hanna (1924) recorded 5 genera and 10 species of Foraminifera from the beds on Cowlitz River. My collection from these same beds contains all the species described by Hanna and Hanna as well as many others. In addition to the foraminifers, other microfossils are present, especially Ostracoda, Bryozoa, Radiolaria, and fish remains.

COLLECTING STATIONS

The 200 feet of beds on Cowlitz River are exposed at low water, generally during September and October, throughout a distance of three quarters of a mile. They dip N. 61° E. at an angle of 10 degrees. The outcrops are not continouus but are limited to two principal exposures, the "upper bluff," locality 233 (Weaver, 1937), and the "lower bluff," locality 232 (Weaver, 1937).[1] Sample one of this collection was taken from the northernmost exposure of locality 233 where a small unnamed stream joins the river. Subsequent samples through no. 37 are from this same locality. Samples 36 and 37 are from a poor exposure, possibly a landslide, below the lowest beds certainly exposed here. Between the two bluffs river gravels and dense vegetation conceal an estimated 45 feet of beds. Sample 38 is from the northernmost exposure of locality 232, and sample 65 from the southernmost. Samples from both localities were taken at three-foot intervals wherever possible and were believed by Weaver (1937, p. 94) to occur on the south flank of the North River-Dryad syncline.

LITHOLOGY

The Cowlitz River beds are predominantly massive gray mudstone—that is partly carbonaceous, micaceous, glauconitic, or silty. Fossiliferous, limy somewhat resistant "reefs," from 8 to 12 inches in thickness, occur in the mudstone at approximate ten foot intervals. and plainly show the apparent dip of the strata. The upper 45 feet of beds are carbonaceous and micaceous mudstone, below which is approxi-

[1] Both of these bluffs are included in Stanford University Locality M-335.

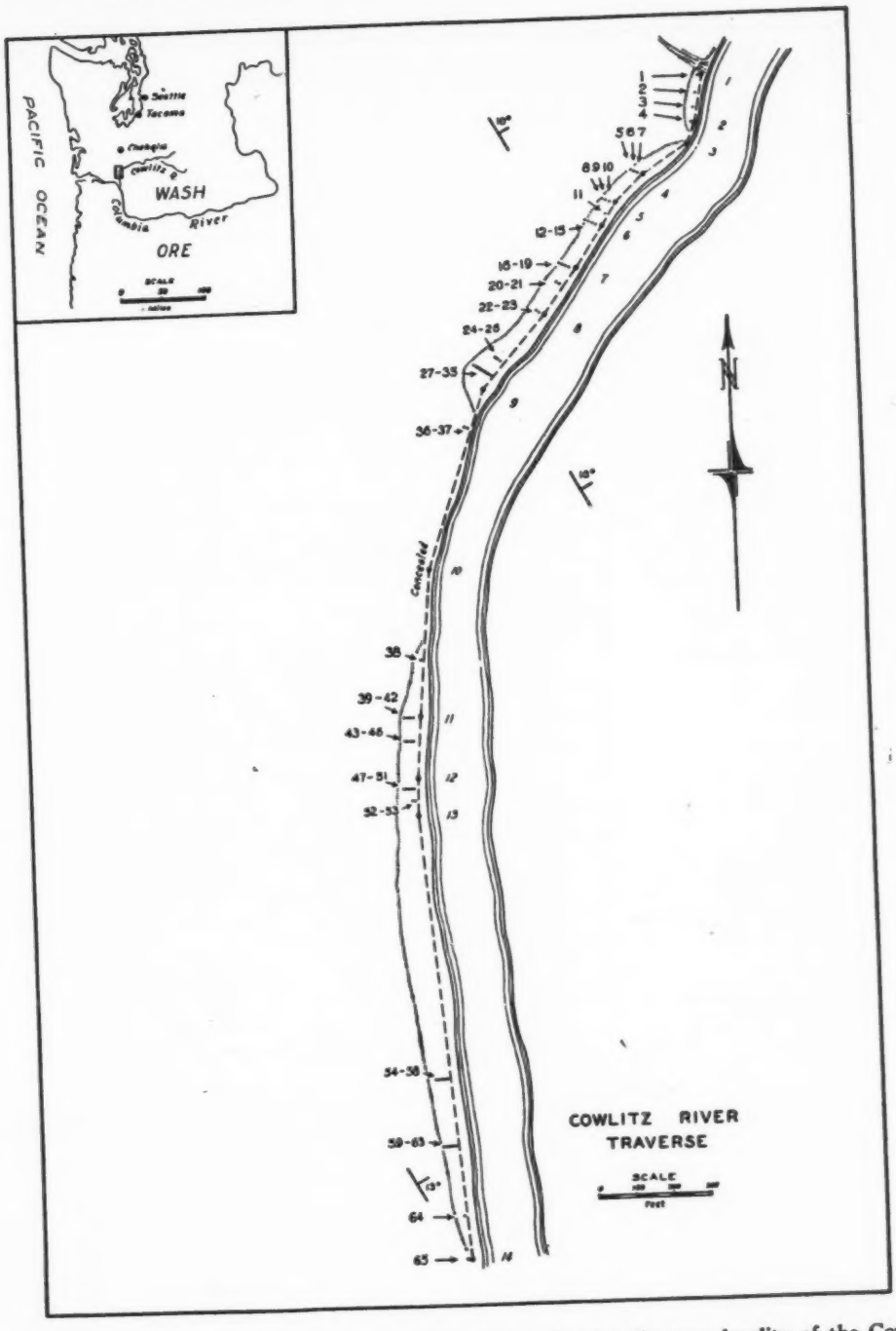


FIG. 1—Index map of western Oregon and Washington showing the type locality of the Cowlitz formation and a detailed sketch map of the collecting stations and traverse along Cowlitz River.

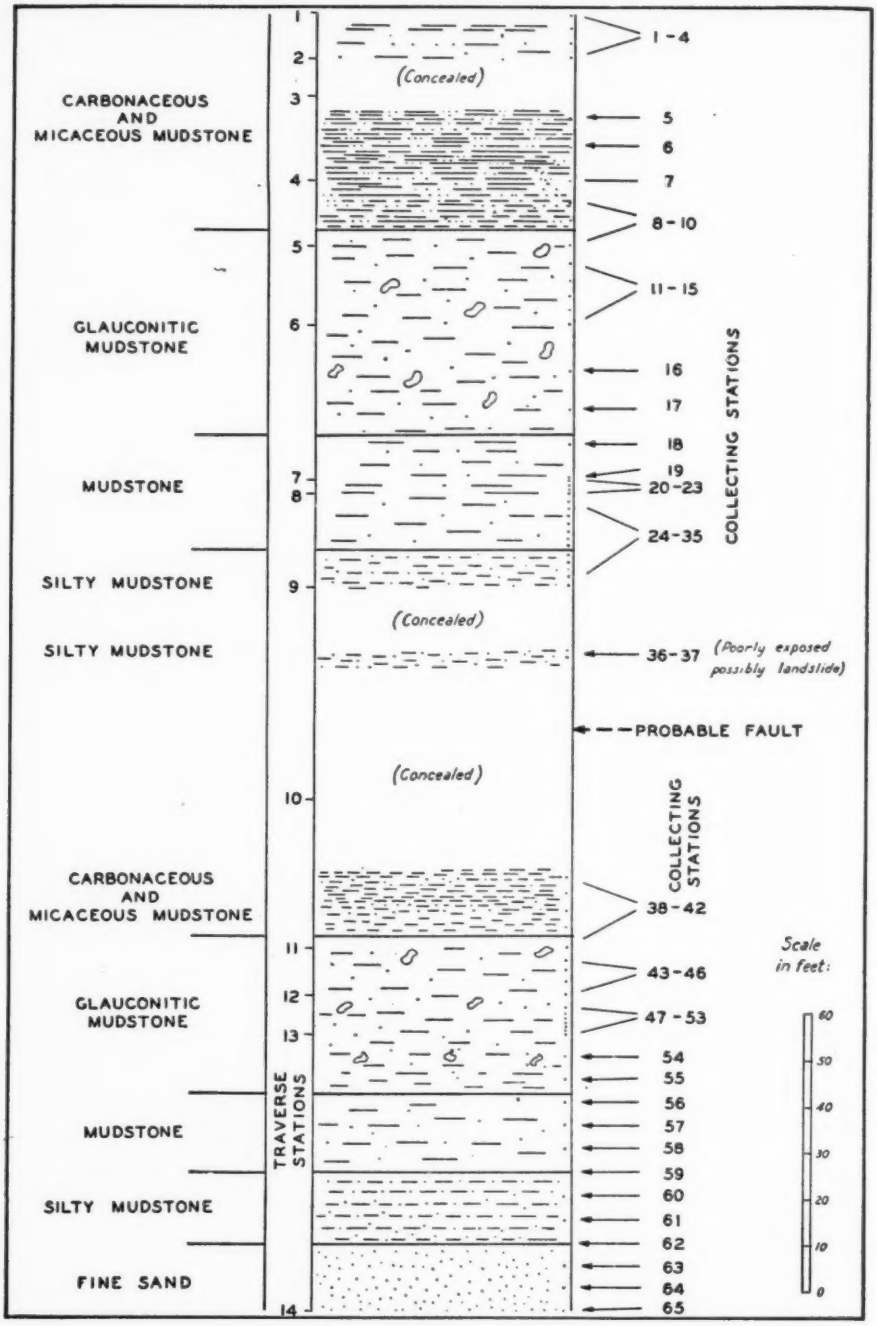


FIG. 2—Columnar section of the Cowlitz formation at the type locality.

mately 40 feet of glauconitic mudstone. Glauconite is abundant enough in samples 14, 15, and 16 to give them a greenish tinge. The third and lowest unit at the "upper bluff" is silty mudstone 15 feet thick.

The lithology and faunal sequence at the "lower bluff" are nearly identical to those at the "upper bluff" except that a 20-foot mollusk-bearing sand underlies the other beds. This similarity might result from recurrent deposition, but the nearly perfect duplication of beds suggests that they have been repeated by faulting. No fault has been observed, however, and if present it must be concealed in the interval between the two bluffs.

material in the mudstone and coarse clastics at the base of the section suggest relatively shallow water. These strata can not be traced to Olequa Creek as they are concealed by vegetation and glacial deposits. Beds considered to be their equivalent, but of different facies, crop out in Olequa Creek, however, where they are overlain by estuarine deposits containing lignitic coal seams suggesting that the shore line was not far distant during their deposition.

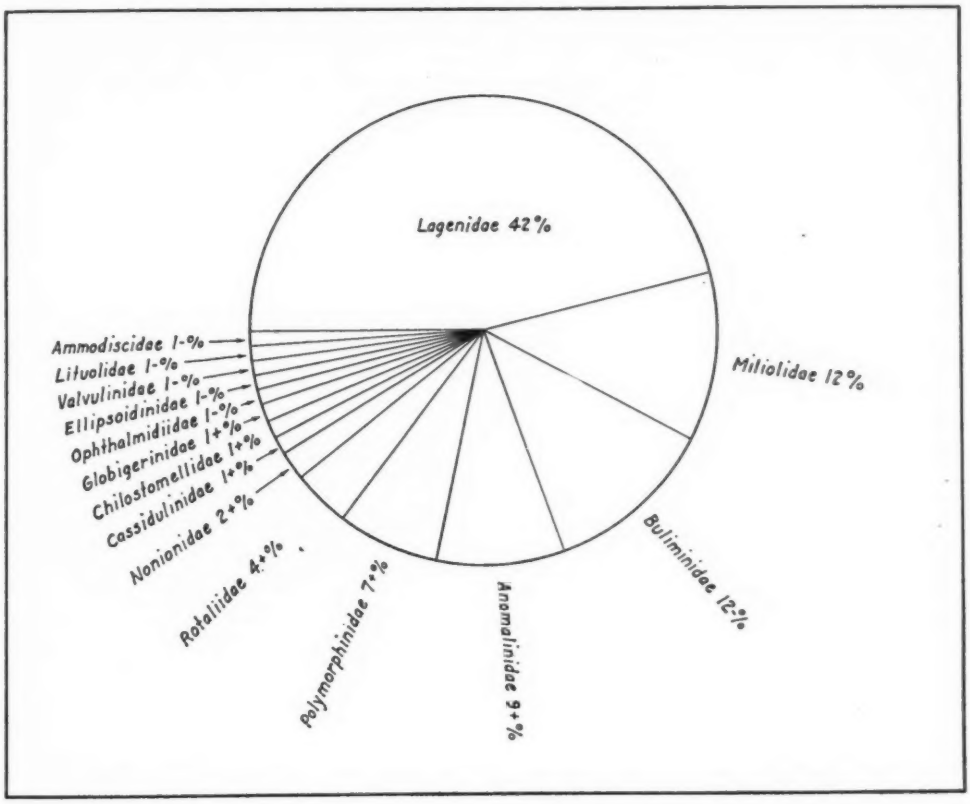


FIG. 3—Shows the percentage of different formaniferal families that make up the faunule from Cowlitz River.

ENVIRONMENT OF DEPOSITION

The Cowlitz River beds are of marine origin but the presence of carbonaceous

The foraminifers suggest deeper water deposition of the type Cowlitz than might be inferred from the lithology. Forty-two per cent of the species belong to the family Lagenidae (fig. 3). Such a fauna may be compared with a recent assemblage, described by Cushman (1921, p. 23) from a depth of 100-300 fathoms off the Philippine Islands. In the same report Cushman

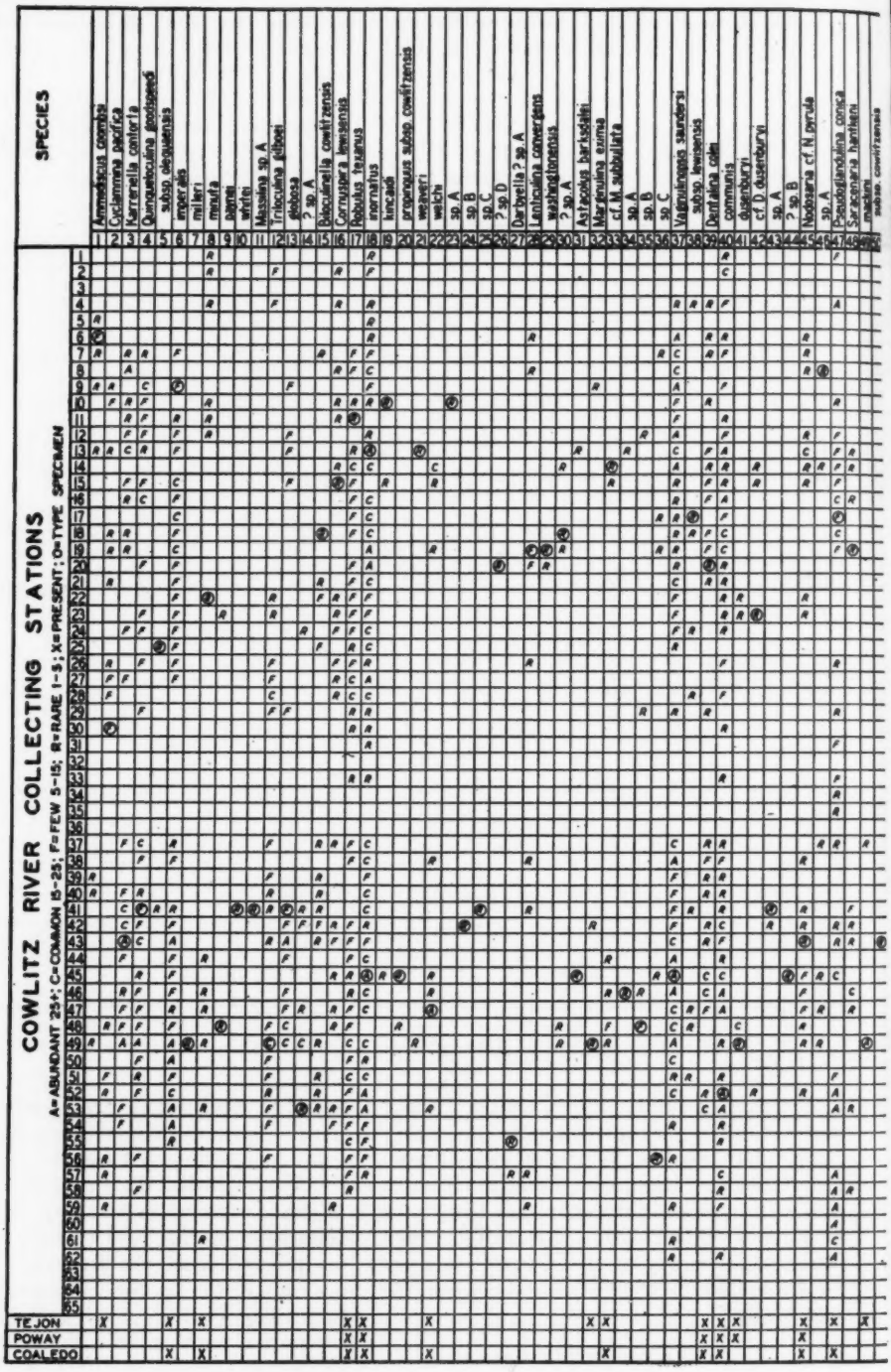


FIG. 4—Distribution of Cowlitz River Foraminifera.

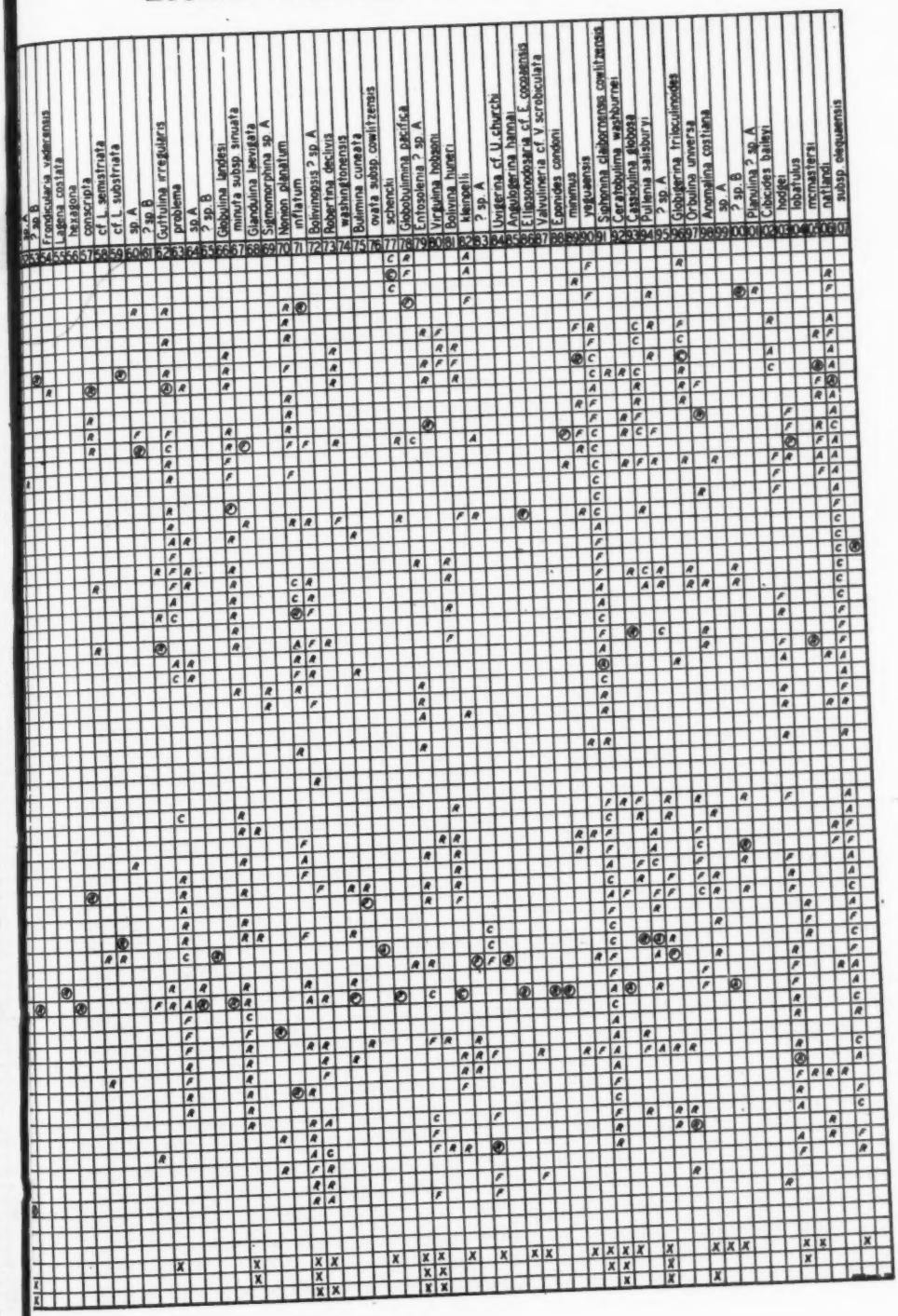

sp. A
sp. B
Frondicularia vaderensis
Lagena costata
hexagona
conscripta
cf. L. semistriata
cf. L. substriata
sp. A
? sp. B
Guttulina irregularis
problema
sp. A
? sp. B
Globulina lacrimi
minuta subsp. sinuata
Glandulina laevigata
Sigmomorphina sp. A
Virgulina pleatum
inflatum
Bolivinopsis ? sp. A
Robertina declivis
washingtonensis
Bulimina cuneata
ovata subsp. cowlitzensis
schenchi
Globobulimina pacifica
Entosolenia ? sp. A
Virgulina hobsoni
Bolivina hureni
kleinpelli
? sp. A
Uvigerina cf. U. churchi
Angulogerina hannai
Ellipsonodosaria cf. E. cooperensis
Valvulineria cf. V. scrobiculata
Eponides condoni
minimus
yaquinaensis
Siphonina claibornensis cowlitzensis
Ceratobulimina washburnei
Cassidulina globosa
Pullenia salisburyi
? sp. A
Globigerina trilocalinoides
Orbulina universa
Anomalina costiana
sp. A
? sp. B
Planulina ? sp. A
Cibicides baileyi
hodgei
lobatulus
mcmasterei
natlandi
subsp. elequensis

FIG. 4, Cont'd.

(1921, p. 26) listed a fauna from "Albatross" station D 5201, Sogood Bay, Southern Leyte Island, 554 fathoms, bottom temperature 11.5° C. that also has a high percentage of lagenids. Norton (1930, p. 368) concluded the Lagenidae are often common at depths of 5 to 60 fathoms, but persist to great depths usually in small numbers. According to Kleinpell (1938, fig. 5), the Miocene Reliz Canyon lagenids were subtropical and lived within the neritic and upper bathyal zones. Although bathymetric data prove a wide range for members of the family, Cushman (1918, p. 3) concluded that its best development is in tropical regions at depths of 100 to 500 fathoms. This is confirmed by a statistical analysis by Visser (1937). The Miliolidae, second in abundance to the Lagenidae, make up 12 per cent of the faunule. This family, according to Norton (1930, p. 339), prefers warm, shallow water of tropical and warm temperate seas at depths down to perhaps 50 to 60 fathoms where the temperature ranges between 20° and 26°C. Notwithstanding the fact that miliolids generally are littoral foraminifers, they are found locally in waters as deep as 554 fathoms. For example, members of the Miliolidae are well represented in Cushman's fauna (1921, p. 23) from "Albatross" station D 5201.

The remainder of the faunule (fig. 5) is composed of about 12 per cent buliminids, 9 per cent anomalinids, 7 per cent polymorphinids, 4 per cent rotalids and 10 per cent of 9 other families. Little reliable ecologic interpretation can be made on the basis of these groups as the first four families have wide bathymetric ranges, and the remaining 9 families are so meagerly represented that it is doubtful they were buried at the locality where they lived during Eocene time.

In summation, the Recent Lagenidae seem to be most abundant at 100 to 500 fathoms in tropical regions, and the miliolidae at from 5 to 60 fathoms in tropical or warm temperate seas. Although the data are conflicting, the absence of lagoonal and littoral species and the scarcity of bathyal forms suggest that, if such limited information can be used for the formulation of an hypothesis, the Cowlitz River faunule lived off a tropical coast in warm to cool marine waters at the outer margin of the neritic zone, down to and perhaps into the upper bathyal zone.

BIOSTRATIGRAPHIC SIGNIFICANCE

At this type locality the Cowlitz formation is of limited thickness, is neither overlain nor underlain by other strata, and is probably faulted, contains a foraminiferal assemblage possibly representing but one faunule. These limitations prevent the recognition of biostratigraphic units of zone or stage magnitude. The local section ideally represents however, a smaller biostratigraphic unit which is designated the *Saracenaria mackini* zonule. The term zonule is here used as Fenton (1928, pp. 20–22) originally defined it:

> The strata or stratum which contains a faunule, its thickness and area being limited by the vertical and horizontal range of that faunule.

Fenton (1928) redefined a faunule as an assemblage of fossil animals associated in one or a few contiguous strata and dominated by the representatives of one community, commonly either an association, or a layer society.

CORRELATION AND AGE

The type Cowlitz has been correlated with the type Tejon of California by Arnold and Hannibal (1913), Dickerson (1915), Weaver (1919) and others on the basis of mollusks. Turner (1938) correlated the Coaledo formation of Oregon with the Cowlitz of Washington and the Tejon of California on the same basis. Laiming (1939) assigned the foraminiferal fauna of Hanna and Hanna (1924) from the type Cowlitz to his *Planulina pseudowuellerstorfi* zone to which he assigned most of the upper 600 feet of the type Tejon.

A close correlation of the Cowlitz River foraminiferal faunule assemblage with other assemblages from the Eocene of the Pacific Coast is difficult because (1) Eocene foraminiferal time-stratigraphic units have not been completely established, (2) the foraminiferal faunas of many Eocene localities are incompletely known or undescribed, (3) the Cowlitz River assemblage is probably only a single faunule whose stratigraphic relations to other faunules is not known.

The type Cowlitz foraminifers, however, probably lived during some portion of the time represented by the upper 900 feet of the type Tejon formation of California. This correlation is based on the study of a collection of 90 samples taken at 10-foot intervals from the type Tejon as exposed in Reed Canyon, the first arroyo east of Tecuya Creek. In this collection, 36 foraminifers out of a total of 76 are conspecific with or analogous to those from the type Cowlitz.

A collection from 360 feet of shale 1790 feet below the top of the Coaledo formation as exposed along the beach between Yokama Point and Cape Gregory, Coos Bay district, Oregon, has 18 species out of a total of 42 that are conspecific with or related to foraminifers from the type Cowlitz and suggests the correlation of these strata.

Fifteen of the 35 species in the foraminiferal fauna described by Cushman and Dusenbury (1934) from the Poway Conglomerate of California (L. S. J. U. Loc. 1150) are present in the type Cowlitz and these beds are probably of similar age.

The Cowlitz River foraminifers have been compared with species reported in the literature from the Gulf Coast and with topotype material from sample No. 1 of Howe (1939) from the Louisiana Cook Mountain Eocene. If comparisons that are made with figured specimens are reliable, and if the Louisiana Cook Mountain material is representative of the entire fauna, the type Cowlitz seems to correlate better with the Cook Mountain Eocene (Claiborne) than with other Gulf Coast Eocene assemblages. Few species from the type Cowlitz and the Cook Mountain are conspecific, but many seem to be closely related.

It is beyond the scope of this paper to correlate the type Cowlitz with European stages. Clark and Vokes (1936) assign the Cowlitz mollusks to their Tejon stage of the Pacific Coast, which they believe is either Auversian or Bartonian. The Foraminifera can offer no more precise testimony.

ACKNOWLEDGMENTS

The author is indebted to Hubert G. Schenck for guidance and encouragement during field studies, paleontological research, and preparation of this report. Charles E. Weaver, Robert M. Kleinpell, Henry V. Howe, G. Dallas Hanna, C. C. Church, Donald D. Hughes, Stanley Carlson, Lesh Forrest, and Pierina Rossello furnished invaluable material and assistance. Joyce Marie Beck, Lois Flathers and Charles McRauen gave technical assistance in preparing the typescript.

The Richfield Oil Corporation permitted the use of some of the supplemental collections studied. Finally, but not least, the writer is grateful to Manley L. Natland for his photographing of the specimens.

TYPES

Holotypes and figured specimens have been deposited in the type collection of Leland Stanford University and paratypes have been deposited in the collections of the California Academy of Sciences and the American Museum of Natural History.

SYSTEMATIC DESCRIPTIONS

Family AMMODISCIDAE

Genus AMMODISCUS Reuss, 1861

AMMODISCUS COOMBSI Beck, n. sp.

Plate 98, figure 1

Test of medium size, planispiral, dorsal side slightly convex, umbonate, ventral side faintly concave, periphery rounded; spiral sutures moderately distinct; composed of approximately three coils; wall finely arenaceous, polished; aperture indistinct. Diameter, 0.70 mm.; thickness, 0.15 mm.

Holotype.—No. 7416, Stanford Univ. Paleo. Type Coll., from station 6.

Remarks.—This species differs from any known *Ammodiscus* in having but three coils in a mature specimen. The umbonate character of the dorsal side suggests that it should be referred to *Ammodiscoides* but the raised umbo is not coiled as in typical *Ammodiscoides.*

Family LITUOLIDAE

Genus CYCLAMMINA H. B. Brady, 1876

CYCLAMMINA PACIFICA Beck, n. sp.

Plate 98, figures 2, 3

Test of medium size, slightly compressed, periphery broadly rounded; chambers 10 or 11, somewhat irregular in size; sutures slightly incised, lighter colored than walls of chambers, nearly radial; wall finely arenaceous, smoothly finished; aperture indis-

tinct. Diameter, 1.28 mm.; thickness, 0.35 mm.

Holotype.—No. 7417, Stanford Univ. Paleo. Type Coll., from station 30.

Remarks.—This species differs from *Cyclammina clarki* (Hanna, 1923, p. 324, pl. 59, fig. 2) in being wider and having a lower apertural face. The figure of *Cyclammina* cf. *C. clarki* Cushman and Hobson (1935, p. 55, pl. 8, figs. 3a, b) closely approaches certain specimens of *C. pacifica*.

Family VALVULINIDAE
Genus KARRERIELLA Cushman, 1933
KARRERIELLA CONTORTA Beck, n. sp.
Plate 98, figures 4, 5

Test twice as long as broad, twisted, slightly compressed, tapering from subacute initial end to greatest breadth at apertural end, periphery broadly rounded; early chambers somewhat indistinct, inflated, last three make up one-half of entire test, increasing regularly in size as added; sutures distinct, moderately depressed, at right angles to long axis of text; wall calcareous, with some arenaceous material, smooth; aperture an elongate opening above base of apertural face, with distinct neck. Length, 0.96 mm.; breadth, 0.40 mm.; thickness, 0.20 mm.

Holotype.—No. 7418, Stanford Univ. Paleo. Type Coll., from station 43.

Remarks.—This species differs from *Karreriella siphonella* Reuss of Cushman (1933, p. 34, pl. 4, figs. 4a, b) in having a more twisted test and a greater amount of inflation of the chambers. It differs from *K. arenasensis* Cushman and Bermudez (1937, p. 5, pl. 1, figs. 20, 21) in the position and shape of the aperture. The chamber arrangement, position, and shape of aperture of this species are typical of *Karreriella;* however, the semicalcareous test is not. Possibly this species should be assigned to another genus, or subgenus.

Family MILIOLIDAE
Genus QUINQUELOCULINA d'Orbigny, 1826
QUINQUELOCULINA GOODSPEEDI Hanna and Hanna
Plate 99, figures 1, 2

Quinqueloculina goodspeedi HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geology, vol. 1, no. 4, p. 58, pl. 13, figs. 3, 4.

Dimensions.—Length, 0.95 mm.; breadth, 0.60 mm.; thickness, 0.28 mm.

Hypotype.—No. 7419, Stanford Univ. Paleo. Type Coll., from station 41.

QUINQUELOCULINA GOODSPEEDI OLEQUAENSIS Beck, n. subsp.
Plate 99, figures 3, 4

Dimensions.—Length, 0.83 mm.; breadth, 0.51 mm.; thickness, 0.18 mm.

Holotype.—No. 7420, Stanford Univ. Paleo. Type Coll., from station 25.

Remarks.—This subspecies is characterized by a smaller test with longitudinal striae extending its entire length.

QUINQUELOCULINA IMPERALIS
Hanna and Hanna
Plate 98, figures 9, 10

Quinqueloculina imperalis HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geology, vol. 1, no. 4, p. 58, pl. 13, figs. 7, 8, 10.

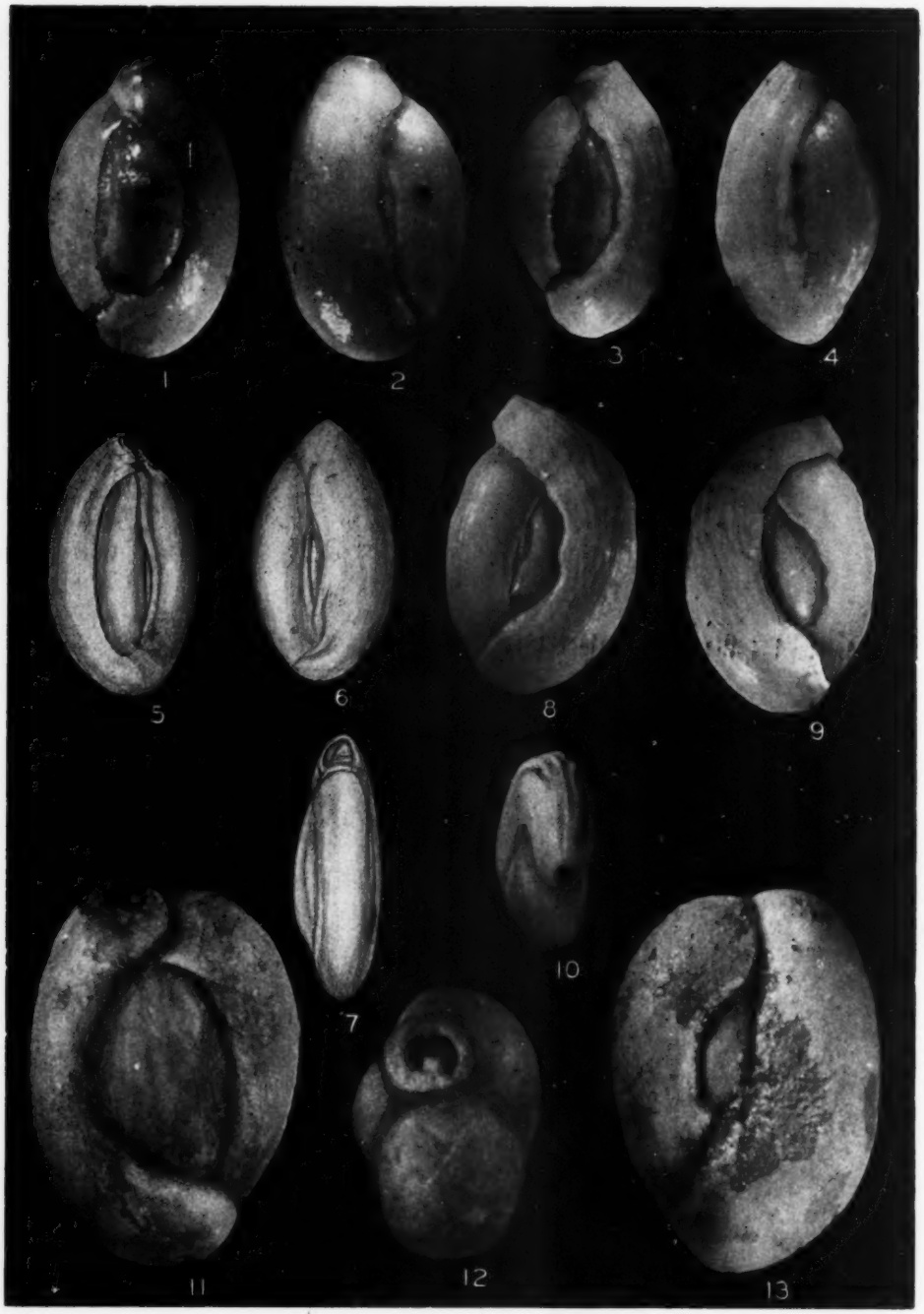
Test large, breadth and length equal, slightly compressed, periphery broadly rounded; adult chambers more inflated than young chambers, each extending far beyond previous ones; sutures distinct, slightly depressed; wall smooth; aperture an elongate oval, truncate at end with large simple tooth-like projecting plate. Length, 1.28 mm.; breadth, 1.25 mm.; thickness, 0.85 mm.

Hypotype.—No. 7421, Stanford Univ. Paleo. Type Coll., from station 9.

EXPLANATION OF PLATE 98

FIGS. *1*—*Ammodiscus coombsi* Beck, n. sp. Holotype, ×50. (p. 591)
2, 3—*Cyclammina pacifica* Beck, n. sp. *2*, Apertural view. *3*, Side view. Holotype, ×40. (p. 591)
4, 5—*Karreriella contorta* Beck, n. sp. *4*, Apertural view. *5*, Side view. Holotype, ×40. (p. 592)
6–8—*Quinqueloculina paynei* Beck, n. sp. *6*, Side view (four chambers). *7*, Side view (three chambers). *8*, Apertural view. Holotype, ×40. (p. 593)
9, 10—*Quinqueloculina imperalis* Hanna and Hanna. *9*, Side view (four chambers). *10*, Side view (three chambers). (p. 592)

Beck, Eocene Foraminifera



Beck, Eocene Foraminifera

Remarks.—The holotype was described by Hanna and Hanna (1924, p. 58) as having a bifid tooth. G. Dallas Hanna has written (1941) that he has reexamined the holotype and topotypes and finds that they all have a simple pointed tooth that is heavy and truncate at its base.

QUINQUELOCULINA MILLERI Beck, n. sp.
Plate 99, figures 8–10

Test moderately large, nearly twice as long as broad, compressed, periphery rounded; chambers distinct, somewhat complanate, each extending far beyond previous ones, outer edge of longest chamber arcuate, inner edge somewhat sinuous; neck greatly extended; sutures distinct, deeply incised; wall of younger chambers faintly striated, older chambers rugose with anastomosing striae on lower portions that progressively develop into several costae toward apertural end; aperture circular with no apparent dentition. Length, 0.95 mm.; breadth, 0.58 mm.; thickness, 0.25 mm.

Holotype.—No. 7422, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—The distinct ornamentation of this species differentiates it from any known *Quinqueloculina*. It resembles *Triloculina natchitochensis* Howe (1939, p. 38, pl. 3, figs. 3–5), but differs in having costae that converge toward the apertural end, and a neck that bends toward the lower portion of the test. *Q. milleri* is a typical *Quinqueloculina*, while *T. natchitochensis* according to Howe (1939) is a questionable *Triloculina*.

QUINQUELOCULINA MINUTA Beck, n. sp.
Plate 99, figures 5–7

Test small, twice as long as broad, moderately compressed, periphery rounded; chambers distinct, somewhat inflated, ends slightly extended; sutures distinct, slightly depressed; wall smooth; aperture not discernible on side showing three chambers, hood-like on opposite side, no apparent dentition. Length, 0.45 mm.; breadth, 0.26 mm.; thickness, 0.15 mm.

Holotype.—No. 7423, Stanford Univ. Paleo. Type Coll., from station 22.

Remarks.—The hood-like aperture of this small species differentiates it from any other *Quinqueloculina*. It resembles the figure of *Miliolina oblonga* (Montagu), after Brady, of Bagg (1912, p. 29, pl. 4, figs. 6a, b), but differs in being smaller and flatter, with no apparent dentition.

QUINQUELOCULINA PAYNEI Beck, n. sp.
Plate 98, figures 6–8

Test large, nearly twice as long as broad, greatest width at center, apertural end nearly as wide, triangular in cross section, periphery broadly rounded; chambers inflated, each extending far beyond previous ones; sutures distinct, slightly depressed; wall pustulate; aperture semicircular, end truncated with narrow simple tooth. Length, 1.18 mm.; breadth, 0.72 mm.; thickness, 0.47 mm.

Holotype.—No. 7424, Stanford Univ. Paleo. Type Coll., from station 48.

Remarks.—This species differs from *Q. goodspeedi* Hanna and Hanna (1924, p. 58, pl. 13, figs. 3, 4) in being larger and having a shorter apertural neck and a pustulate wall.

QUINQUELOCULINA WHITEI Beck, n. sp.
Plate 99, figures 11–13

Test large, nearly twice as long as broad, moderately compressed, periphery broadly rounded; chambers distinct, extending con-

EXPLANATION OF PLATE 99

FIGS. *1, 2*—*Quinqueloculina goodspeedi* Hanna and Hanna. *1*, Side view (four chambers). *2*, Side view (three chambers), ×40. (p. 592)

3, 4—*Quinqueloculina goodspeedi* Hanna and Hanna subspecies *olequaensis* Beck, n. subsp. *3*, Side view (four chambers). *4*, Side view (three chambers). Holotype, ×45. (p. 592)

5–7—*Quinqueloculina minuta* Beck, n. sp. *5*, Side view (four chambers). *6*, Side view (three chambers). *7*, Apertural view. Holotype, ×75. (p. 593)

8–10—*Quinqueloculina milleri* Beck, n. sp. *8*, Side view (four chambers). *9*, Side view (three chambers). *10*, Apertural view. Holotype, ×40. (p. 593)

11–13—*Quinqueloculina whitei* Beck, n. sp. *11*, Side view (four chambers). *12*, Apertural view. *13*, Side view (three chambers). Holotype, ×40. (p. 593)

siderably beyond previous ones, very wide at apertural end, extending into very short semi-elliptical neck; sutures distinct, deeply incised; wall coated with thin veneer of arenaceous material; aperture nearly circular with heavy simple tooth. Length, 1.30 mm.; breadth, 0.90 mm.; thickness, 0.64 mm.

Holotype.—No. 7425, Stanford Univ. Paleo. Type Coll., from station 41.

Remarks.—This species differs from *Q. paynei* Beck in having a thick simple tooth and a smoother wall coated with a thin veneer of arenaceous material.

QUINQUELOCULINA sp.
Plate 100, figures 1, 2

This single well-preserved specimen was lost after it had been photographed. It is figured for future reference.

Genus MASSILINA Schlumberger, 1893
MASSILINA sp. A
Plate 100, figures 5, 6

Dimensions.—Length, 1.05 mm.; breadth, 0.78 mm.; thickness, 0.32 mm.

Figured specimen.—No. 7426, Stanford Univ. Paleo. Type Coll., from station 41.

Remarks.—One specimen was found which is unique in having a groove in the oldest chamber. Whether this is a typical feature or a fracture is uncertain; consequently, a specific determination is hazardous.

Genus TRILOCULINA d'Orbigny, 1826
TRILOCULINA GILBOEI Beck, n. sp.
Plate 101, figures 1–3

Test large, breadth and length equal, periphery broadly rounded; chambers strongly inflated, each extending beyond previous ones, sutures distinct, slightly depressed, wall smooth, coated with a thin layer of whitish-gray material; aperture semitriangular, truncated at base of last chamber, with large club-shaped projecting simple tooth. Length, 1.10 mm.; breadth, 1.30 mm.; thickness, 0.90 mm.

Holotype.—No. 7427, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This species differs from *T. globosa* (Hanna and Hanna, 1924) in being nearly twice as large and having a simple club-shaped tooth.

TRILOCULINA GLOBOSA
(Hanna and Hanna)
Plate 100, figures 3, 4

Quinqueloculina globosa HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geology, vol. 1, no. 4, p. 58, pl. 13, figs. 1, 2.

Dimensions.—Length, 0.60 mm.; breadth, 0.57 mm.; thickness, 0.45 mm.

Hypotype.—No. 7428, Stanford Univ. Paleo. Type Coll., from station 41.

Remarks.—The original description and figure of the holotype show it to be a three-chambered miliolid and therefore it should be referred to *Triloculina*.

TRILOCULINA? sp. A
Plate 100, figures 7–9

Dimensions.—Length, 1.35 mm.; breadth, 0.90 mm.; thickness, 0.60 mm.

Figured specimen.—No. 7429, Stanford Univ. Paleo. Type Coll., from station 53.

Remarks.—Several specimens have three chambers on each side and, consequently, might be referred to either *Quinqueloculina* or *Triloculina*.

Genus BILOCULINELLA Wiesner, 1931
BILOCULINELLA COWLITZENSIS
Beck, n. sp.
Plate 101, figures 6, 7

Test small, slightly longer than broad, breadth and thickness about equal, periphery broadly rounded; chambers distinct, much inflated, last two making up entire exterior; sutures distinct, depressed; wall smooth; aperture a long, narrow arc, with broad flat tooth. Length, 0.62 mm.; breadth, 0.55 mm.; thickness, 0.52 mm.

Holotype.—No. 7430, Stanford Univ. Paleo. Type Coll., from station 18.

Remarks.—This species resembles the figures of *Biloculina ringens* (Lamarck) of Bagg (1912, p. 25, pl. 1, figs. 12–16) but differs in being smaller and having a differently shaped aperture and tooth.

Family OPHTHALMIDIIDAE
Genus CORNUSPIRA Schultze, 1854
CORNUSPIRA LEWISENSIS Beck, n. sp.
Plate 101, figures 4, 5

Test large, planispiral, evolute, both sides deeply excavated at proloculum; composed of 8 to 10 coils, last somewhat complanate,

forming approximately one-third of diameter of test; sutures spiral, deeply incised, slightly hyaline; wall finely calcareous, imperforate; aperture at open end of last chamber. Diameter, 1.08 mm.; thickness, 0.22 mm.

Holotype.—No. 7431 Stanford Univ. Paleo. Type Coll., from collecting station 15.

Remarks.—This species resembles the figure of *C. byramensis* Cushman (1935, p. 27, pl. 4, figs. 4a, b) but differs in being more than twice as large. It also seems to be related to *C. olygogyra* Hantken of Howe (1939, p. 39, pl. 3, figs. 9, 10) from the Cook Mountain Eocene.

Family LAGENIDAE
Genus ROBULUS Montfort, 1808
ROBULUS INORNATUS (d'Orbigny) 1846
Plate 104, figures 1–4, 10, 14

Robulina inornata D'ORBIGNY, 1846, Foram Foss. Bass. Tert. Vienne, p. 102, pl. 4, figs. 25, 26.
Cristellaria rotulata (LAMARCK). HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geol., vol. 1, no. 4, p. 61, pl. 13, figs. 14, 19, 20.

Dimensions.—Length, 75–92 mm.; breadth, 65–80 mm.; thickness, 30–50 mm.

Hypotype.—No. 7433, Stanford Univ. Paleo. Type Coll., from station 13.

Remarks.—Abundant but variable specimens seemingly are referable to *R. inornatus.*

ROBULUS KINCAIDI Beck, n. sp.
Plate 102, figures 1, 7

Test large, closely coiled throughout, periphery acute, sharply keeled; chambers fairly distinct, comparatively few, five in last coil, last making up nearly one-half of entire test; sutures distinct when wet, flush with surface; wall smooth; outer margin of apertural face raised; aperture radiate. Length, 1.00 mm.; breadth, 0.82 mm.; thickness, 0.60 mm.

Holotype.—No. 7434, Stanford Univ. Paleo Type Coll., from station 10.

Remarks.—This species differs from any known *Robulus* in having a last chamber that makes up nearly one-half of the entire test. It is somewhat similar to *R. melvilli* Cushman and Renz (1941), but differs in having a larger last chamber, a more rounded periphery and by not being umbonate.

ROBULUS PROPINQUUS COWLITZENSIS Beck, n. subsp.
Plate 104, figures 6, 12

Dimensions.—Length, 0.45 mm.; breadth, 0.25 mm.; thickness, 0.10 mm.

Holotype.—No. 7435, Stanford Univ. Paleo. Type Coll., from station 45.

Remarks.—This subspecies differs from the typical form in being shorter and in having the later sutures incised, and a narrower, higher apertural face.

ROBULUS TEXANUS (Cushman and Applin)
Plate 103, figures 1, 2, 4, 5

Cristellaria articulata texana CUSHMAN and APPLIN, 1926, Am. Assoc. Petroleum Geologists Bull., vol. 10, p. 170, pl. 8, figs. 1, 2.

Test large, loosely coiled, with distinct umbo thickest in umbonal region; chambers distinct, 9 to 12 in last coil, later coils increasing in height; sutures distinct, flush with surface, moderately curved; wall smooth; apertural face slightly convex, aperture at peripheral angle, radiate, strongly produced. Length, 1.55 mm.; breadth, 1.25 mm.; thickness, 0.60 mm.

Hypotype.—No. 7432, Stanford Univ. Paleo. Type Coll., from station 11.

Remarks.—This species is identical with a variety of *Robulus articulatus* (Reuss, 1863) figured by Cushman and Applin (1926, pl. 8, fig. 1) from the Texas Jackson. It differs from the original figure of *R. articulatus* in having more and narrower chambers and being more loosely coiled; these differences are believed to be sufficient to warrant considering it a distinct species.

ROBULUS WEAVERI Beck, n. sp.
Plate 103, figures 3, 8

Test large, higher than broad, thickest through umbonal region, completely involute, periphery acute with narrow keel developed on lower portion; chambers distinct, flush with surface, moderately curved, earlier apertures visible at periphery; wall smooth, apertural face concave, asymmetric, typical robuline aperture. Length, 1.38 mm.; breadth, 1.00 mm.; thickness, 0.65 mm.

Holotype.—No. 7436, Stanford Univ. Paleo. Type Coll., from station 13.

Remarks.—The distorted appearance of the test suggests a crushed or aberrant form but the asymmetrical apertural face is typical of a number of specimens from different samples and probably has specific importance. The outline of the test is similar to that of *R. isidis* (Schwager) of Cushman and Ponton (1932, p. 52, pl. 7, figs. 2a, b) but this species has a greater number of chambers in addition to its asymmetrical apertural face.

ROBULUS WELCHI Church
Plate 102, figures 4, 8

Robulus welchi CHURCH, 1931, *Figured in* Mining in California, vol. 27, no. 2, p. 213, pl. C, Figs. 13, 14; *Described in* 1941, California Dept. Nat. Resources, Bull. 118, pt. 2, p. 182.

Dimensions.—Length, 0.48 mm.; breadth, 0.40 mm.; thickness, 0.10 mm.

Hypotype.—No. 7437, Stanford Univ. Paleo. Type Coll., from station 47.

Remarks.—This distinctive, widespread species is common in the type Cowlitz. It also occurs commonly in the "Markley," and rarely in the Tejon formations of California. It is present in the Bassendorf and Coaledo formations of Oregon.

ROBULUS sp. A
Plate 101, figures 9, 10

Dimensions.—Length, 1.42 mm.; breadth, 1.15 mm.; thickness, 0.75 mm.

Figured specimen.—No. 7438, Stanford Univ. Paleo. Type Coll., from station 10.

Remarks.—A single large specimen has a grooved periphery that is strongly lobulate in its later development. Other specimens are needed for specific identification.

ROBULUS sp. B
Plate 102, figures 2, 3

Dimensions.—Diameter, 1.20 mm.; thickness, 0.51 mm.

Figured specimen.—No. 7439, Stanford Univ. Paleo. Type Coll., from station 42.

Remarks.—A single specimen seems to be related to *Robulus arcuato-striatus carolinianus* Cushman (1933, p. 4, pl. 1, figs. 9a, b).

ROBULUS sp. C
Plate 103, figures 6, 7

Test large, close-coiled; periphery acute, sharply keeled; chambers five, fairly distinct, uniformly shaped, increasing slightly in size as added; sutures distinct, earliest two faintly raised, last apparently bifurcate at point half way between umbo and periphery; wall smooth; apertural face slightly concave; aperture typically robuline, radiate portion projecting upward, outward. Length, 1.10 mm.; breadth, 1.00 mm.; thickness, 0.50 mm.

Figured specimen.—No. 7440, Stanford Univ. Paleo. Type Coll., from station 41.

Remarks.—The size, outline and apertural characters of this single specimen are similar to those of *Robulus* sp. A, but it differs in having an acute keel, and apparent bifurcation of the last suture.

ROBULUS? sp. D
Plate 102, figures 5, 6

Test unusually large, thickest through umbonal region, initial chambers close coiled, later ones tending to uncoil, periphery subacute, irregularly lobulate; chambers 7 or more, increasing in size as added; sutures distinct, strongly raised, early ones more curved; wall slightly roughened; apertural face high, triangular, slightly concave, aperture broken. Length, 2.30 mm.; breadth, 1.10 mm.

Figured specimen.—No. 7441, Stanford Univ. Paleo. Type Coll., from station 20.

Remarks.—The later chambers of this single large specimen are broken.

Genus DARBYELLA Howe and Wallace, 1933
DARBYELLA? sp. A
Plate 104, figures 8, 11, 13

Dimensions.—Length, 0.65 mm.; breadth, 0.65 mm.; thickness, 0.45 mm.

Figured specimen.—No. 7442, Stanford Univ. Paleo. Type Coll., from station 55.

Remarks.—A few specimens have a robuline aperture rather than the typical slit characterizing *Darbyella* but in all other characters they are typical of that genus. A large suite of specimens might prove this form represent a new genus.

Genus LENTICULINA Lamarck, 1804
LENTICULINA CONVERGENS
(Bornemann) 1885
Plate 104, figures 5, 9

Cristellaria convergens BORNEMANN, 1885, Deutsch. geol. Gesell. Zeitschr., vol. 7, p. 327, pl. 13, figs. 16, 17.

Dimensions.—Length, 0.45 mm.; breadth, 0.38 mm.; thickness, 0.25 mm.

Hypotype.—No. 7443, Stanford Univ. Paleo. Type Coll., from station 21.

Remarks.—This well known species is common in the Cowlitz River material.

LENTICULINA WASHINGTONENSIS
Beck, n. sp.
Plate 104, figures 18, 21

Test robust, periphery slightly keeled, loosely coiled, thickest through umbonal region; chambers distinct, four, last three nearly equal in size; sutures distinct, faintly depressed; wall smooth, polished; apertural face strongly convex, making up more than two-thirds of test; aperture extending upward. Length, 1.05 mm.; breadth, 0.85 mm.; thickness, 0.60 mm.

Holotype.—No. 7444, Stanford Univ. Paleo. Type Coll., from station 19.

Remarks.—The figured specimen has been compared with the original figure of *Lenticulina crassa* (d'Orbigny). It differs in having fewer, larger chambers and a higher apertural face, but it is identical with the figure and topotypes of *L. crassa* (d'Orbigny) of Cushman and Schenck (1928) from Oregon which is considered to be a synonym.

LENTICULINA? sp. A
Plate 101, figure 8

Dimensions.—Length, 1.40 mm.; breadth, 1.10 mm.; thickness, 0.65 mm.

Figured specimen.—No. 7445, Stanford Univ. Paleo. Type Coll., from station 18.

Remarks.—Approximately 7 chambers present in adult; sutures thick, raised at umbilical region, becoming thinner, lower toward periphery, apertural portion broken.

Genus ASTACOLUS Montfort, 1808
ASTACOLUS BARKSDALEI Beck, n. sp.
Plate 104, figure 17

Test compressed, periphery slightly keeled; chambers eight or nine, early ones short, closely coiled, later ones increasing gradually in length, tending to uncoil; sutures distinct, limbate, later ones slightly raised, wall smooth; aperture radiate, protruding at peripheral angle, apertural face flush with sides. Length, 0.42 mm.; breadth, 0.28 mm.; thickness, 0.15 mm.

Holotype.—No. 7446, Stanford Univ. Paleo. Type Coll., from station 45.

Remarks.—This species closely resembles the figure of *Planularia winniana* Howe (1939, p. 42, pl. 4, fig. 7) but differs in having a greater number of chambers, and having later sutures which are raised and more oblique to the long axis of the test.

Genus MARGINULINA d'Orbigny, 1826
MARGINULINA EXIMIA Neugeboren
Plate 104, figures 15, 16

Marginulina eximia NEUGEBOREN, 1851, Siebenbürg. Ver. Naturwiss. Verh. u. Mitt., p. 129, pl. 4, fig. 17.

Test of medium size, elongate, subcylindrical, periphery rounded, middle portion nearly circular in transverse section; chambers 7, first two closely coiled, small, last smaller than preceding one; sutures flush with surface; wall smooth, polished; aperture radiate, produced. Length, 0.70 mm.; breadth, 0.26 mm.; thickness, 0.24 mm.

Hypotype.—No. 7447, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—Cushman and Ponton (1932, p. 54, pl. 7, figs. 8a, b) record *M. eximia* from the Wilcox of Alabama. Their figured specimen is very similar to the Cowlitz specimens.

MARGINULIA cf. M. SUBBULLATA Hantken
Plate 104, figure 7

Dimensions.—Length, 0.88 mm.; breadth, 0.30 mm.; thickness, 0.30 mm.

Hypotype.—No. 7448, Stanford Univ. Paleo. Type Coll., from station 14.

Remarks.—Specimens are rare and variable and identification is uncertain. The figured specimen has not been compared with the original figure of *M. subbullata* Hantken (1876) but it is similar to *M. subbullata* Hantken of Cushman (1939, pl. 9, figs. 30, 31).

MARGINULINA sp. A
Plate 104, figures 19, 20

Test of medium size, elongate, compressed, periphery subacute; later chambers considerably wider than earlier ones, 6 or 7 in number; sutures of initial portion flush with surface, later ones slightly impressed;

wall smooth, polished; aperture radiate, produced. Length, 0.58 mm.; breadth, 0.32 mm.; thickness, 0.25 mm.

Figured specimen.—No. 7449, Stanford Univ. Paleo. Type Coll., from station 46.

Remarks.—Specimens are too few to be specifically identified.

MARGINULINA sp. B
Plate 105, figures 6, 7

Test of medium size, elongate, subcylindrical, periphery rounded, circular in transverse section; chambers 6, early ones small, later ones increase in size as added, inflated, last chamber making up nearly one-third of test; sutures distinct, very slightly impressed, bending sharply upward toward convex periphery; wall smooth, polished; aperture radiate, strongly produced. Length, 0.83 mm.; breadth, 0.35 mm.; thickness, 0.35 mm.

Figured specimen.—No. 7450, Stanford Univ. Paleo. Type Coll., from station 48.

MARGINULINA sp. C
Plate 105, figures 15, 16

Test small, obese, periphery rounded, cylindrical in transverse section; chambers 4, last making up nearly one-half of entire test; sutures slightly impressed, distinct; wall smooth, polished, in last chamber somewhat hyaline; aperture radiate, strongly produced. Length, 0.42 mm.; breadth, 0.30 mm.; thickness, 0.27 mm.

Figured specimen.—No. 7451, Stanford Univ. Paleo. Type Coll., from station 56.

Genus VAGINULINOPSIS Silvestri, 1904
VAGINULINOPSIS SAUNDERSI
(Hanna and Hanna)
Plate 105, figures 1, 2, 4, 5, 10

Cristellaria saundersi HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geol., vol. 1, no. 4, p. 61, pl. 13, figs. 5, 6, 15.

Dimensions.—Length, 1.50 mm.; breadth, 0.65 mm.; thickness, 0.40 mm.

Hypotype.—No. 7452, Stanford Univ. Paleo. Type Coll., from station 45.

Remarks.—This species is found abundantly in the Cowlitz beds and it shows much variation. Among more than 100 specimens from collecting station 46 some are strongly keeled, others have no keel; some are long, straight, and narrow, others are short and coiled; some have strongly inflated last chambers, the last chambers of others are compressed; and the sutures are much more thickened and raised in some than in others. This series includes specimens that bridge the gaps between the most diverse forms.

G. D. Hanna and C. C. Church (1937, p. 530) differentiate *V. saundersi* from "*Marginulina vacavillensis*" by its greater elongation, heavier sutures and the definite carina on the inner uncoiled edge, but some specimens lack one or all of these characteristics. Generally *V. saundersi* is more elongate than "*M. vacavillensis.*"

For a discussion of the genus *Vaginulinopsis* see Thalmann (1938) and Toulmin (1941, p. 582).

VAGINULINOPSIS SAUNDERSI LEWISENSIS
Beck, n. subsp.
Plate 105, figures 3, 13

Dimensions.—Length, 0.85 mm.; breadth, 0.45 mm.; thickness, 0.23 mm.

Holotype.—No. 7453, Stanford Univ. Paleo. Type Coll., from station 17.

Remarks.—This subspecies differs from the typical form in its smaller adult test, more compressed and fewer chambers, and unelevated sutures.

DENTALINA COLEI Cushman and Dusenbury
Plate 105, figure 18

Dentalina colei CUSHMAN and DUSENBURY, 1934, Cushman Lab. Foram. Research Contr., vol. 10, pt. 3, p. 54, pl. 7, figs. 10, 11, 12.

Dimensions.—Length, 0.98 mm.; diameter, 0.23 mm.

Hypotype.—No. 7454, Stanford Univ. Paleo. Type Coll., from station 20.

Genus DENTALINA d'Orbigny, 1826
DENTALINA COMMUNIS (d'Orbigny)
Plate 105, figure 22

Nodosaria (*Dentalina*) *communis* D'ORBIGNY, 1826, Soc. Annales sci. nat., vol. 7, p. 254, no. 35.

Nodosaria roemeri HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geol., vol. 1, no. 4, p. 60, pl. 13, fig. 21.

Test elongate, slender, slightly curved, gradually tapering from acute or spinose initial end; chambers in adult 8, early ones longer than broad, later ones subequal, subglobular; sutures distinct, of clear shell ma-

terial, slightly incised, strongly oblique at initial end, tending to be less so toward apertural end; wall smooth, somewhat hyaline; apertural end strongly produced. Length, 1.25 mm.; diameter, 0.25 mm.

Hypotype.—No. 7455, Stanford Univ. Paleo. Type Coll., from station 52.

DENTALINA DUSENBURYI Beck, n. sp.
Plate 105, figures 20, 23

Test elongate, slender, slightly curved; number of chambers in adult unknown, three present in immature form here figured, subequal, inflated, approximately 20 well developed costae on basal portion terminating at or just beyond sutures; sutures distinct, deeply incised, of clear shell material, nearly normal to long axis; wall smooth, aperture typically radiate, considerably off center, strongly produced. Length, 1.15 mm.; diameter, 0.40 mm.

Holotype.—No. 7456, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—Specimens from the Poway conglomerate listed by Cushman and Dusenbury (1934) as *Dentalina capitata?* are identical to the Cowlitz specimens. They resemble "*D. capitata* (Boll) of authors," but differ in having more inflation of the chambers, deeper incision of the sutures, fewer and heavier costae, and more eccentric apertures.

DENTALINA cf. D. DUSENBURYI Beck
Plate 105, figure 14

Dimensions.—Length, 1.95+ mm.; diameter, 0.50 mm.

Hypotype.—No. 7457, Stanford Univ. Paleo. Type Coll., from station 23.

Remarks.—A few broken and incomplete specimens having incipient costae at the base of the chambers seem to be related to *D. dusenburyi.* More complete specimens are needed for definite identification.

DENTALINA sp. A
Plate 105, figures 11, 17

Test elongate, slender, slightly curved, initial end subacute, becoming progressively wider toward apertural end; chambers 7, early ones small, wider than high, later ones subequal, last two make up nearly one-half of entire test; first three sutures somewhat indistinct, flush with surface, later three distinct, incised, nearly normal to long axis; wall smooth; aperture off center, radiate, strongly produced. Length, 0.73 mm.; diameter, 0.20 mm.

Figured specimen.—No. 7458, Stanford Univ. Paleo. Type Coll., from station 41.

Remarks.—This rare form can not be specifically identified. More specimens are needed to ascertain if the specimen figured is typical.

DENTALINA? sp. B
Plate 105, figure 9

Dimensions.—Length, 0.58 mm.; diameter, 0.15 mm.

Figured specimen.—No. 7459, Stanford Univ. Paleo. Type Coll., from station 45.

Remarks.—The single specimen is probably a megalosperic form. More are needed for its identification.

Genus NODOSARIA Lamarck, 1812
NODOSARIA cf. N. PYRULA d'Orbigny
Plate 105, figures 19, 21

Nodosaria pyrula D'ORBIGNY, 1826, Annales sci. nat. vol. 7, p. 253, no. 13.

Dimensions.—Length, 0.82+ mm.; diameter, 0.22 mm.

Hypotype.—No. 7460, Stanford Univ. Paleo. Type Coll., from station 43.

Remarks.—A large number of incomplete specimens posses only one chamber and occasionally the broken portion of another. They seem to be closely related to *N. pyrula.*

NODOSARIA sp. A
Plate 105, figure 8

Dimensions.—Length, 0.45 mm.; diameter, 0.09 mm.

Figured specimen.—No. 7461, Stanford Univ. Paleo. Type Coll., from station 8.

Remarks.—A few incomplete specimens are similar to *Nodosaria* cf. *N. pyrula* but are smaller.

Genus PSEUDOGLANDULINA Cushman, 1929
PSEUDOGLANDULINA CONICA (Neugeboren)

Plate 105, figure 12

Glandulina conica NEUGEBOREN, 1850, Siebenburg. Ver. Naturwiss. Verh. u. Mitt. vol. 1, p. 51, pl. 1, figs. 5 a, b.

Nodosaria laevigata HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geol., vol. 1, no. 4, p. 59, pl. 13, fig. 9.

Test medium-sized, elongate to fusiform; chambers five, early ones wider than high, last makes up nearly half of test; sutures moderately distinct, first two flush with surface, last two slightly incised, normal to long axis; wall smooth; aperture produced, radiate, in center of test. Length, 0.80 mm.; diameter, 0.33 mm.

Hypotype.—No. 7462, Stanford Univ. Paleo. Type Coll., from station 17.

Remarks.—This common Cowlitz species varies greatly in the size and shape of its chambers; but no differences are consistent enough to permit its subdivision into distinct species or varieties. Cushman and Barksdale (1930, p. 65, pl. 12, figs. 1, 2, 3) figure *P. conica* from Martinez, California. Their specimens also are variable.

Genus SARACENARIA Defrance, 1824

SARACENARIA HANTKENI Cushman

Plate 106, figures 9, 12

Saracenaria arcuata hantkeni CUSHMAN, 1933, Cushman Lab. Foram. Research Contr., vol. 9, pt. 1, p. 4, pl. 1, figs. 11, 12.

Dimensions.—Length, 1.20 mm.; breadth, 0.48 mm.; thickness, 0.48 mm.

Hypotype.—No. 7463, Stanford Univ. Paleo. Type Coll., from station 19.

Remarks.—The Cowlitz specimens are identical with those of Cushman (1933) from the Cooper marl. This form is believed to be a distinct species, because the original figure of *Saracenaria arcuata* (d'Orbigny, 1846) shows a more closely coiled initial end, a more strongly bent convex periphery, the later sutures to be more oblique to the long axis of the test, and a less triangular cross section.

SARACENARIA MACKINI Beck, n. sp.

Plate 106, figures 1, 5, 7

Test twice as long as broad, periphery subacute, triangular in transverse section, early portion close-coiled, later becoming uncoiled; chambers usually eight to 10, uncoiled ones subequal; sutures distinct, raised, first 4 or 5 broken into nodes; wall polished; aperture radiate. Length, 1.40 mm.; breadth, 0.65 mm.; thickness, 0.65 mm.

Holotype.—No. 7464, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This species differs from *S. ornatula* Cushman and Bermudez (1937, p. 11, pl. 1, fig. 35) in having heavier costae, more undercutting at the base of the chambers, and greater curvature of the test.

SARACENARIA MACKINI COWLITZENSIS Beck, n. subsp.

Plate 106, figures 18, 19

Dimensions.—Length, 0.68 mm.; breadth, 0.42 mm.; thickness, 0.42 mm.

Holotype.—No. 7465, Stanford Univ. Paleo. Type Coll., from station 43.

Remarks.—A single specimen resembles immature forms of *S. mackini* Beck, but differs in being more involute, heavier noded and with more chambers.

Genus VAGINULINA d'Orbigny, 1826

VAGINULINA cf. V. WRIGHTI Cole

Plate 107, figure 34

Test medium-sized, elongate, subcircular in cross section; chambers 6, first two small, last two forming one-half of entire test; sutures moderately distinct, later ones slightly incised; aperture radiate. Length, 0.90 mm.; diameter, 0.30 mm.

Hypotype.—No. 7466, Stanford Univ. Paleo. Type Coll., from station 62.

Remarks.—These rare specimens seem to be closely related to *V. wrighti* Cole of Howe (1939, p. 49) from the Cook Mountain Eocene of Louisiana.

VAGINULINA sp. A

Plate 106, figures 2, 4

Test medium-sized, compressed; periphery rounded, one margin nearly straight, other

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EXPLANATION OF PLATE 100

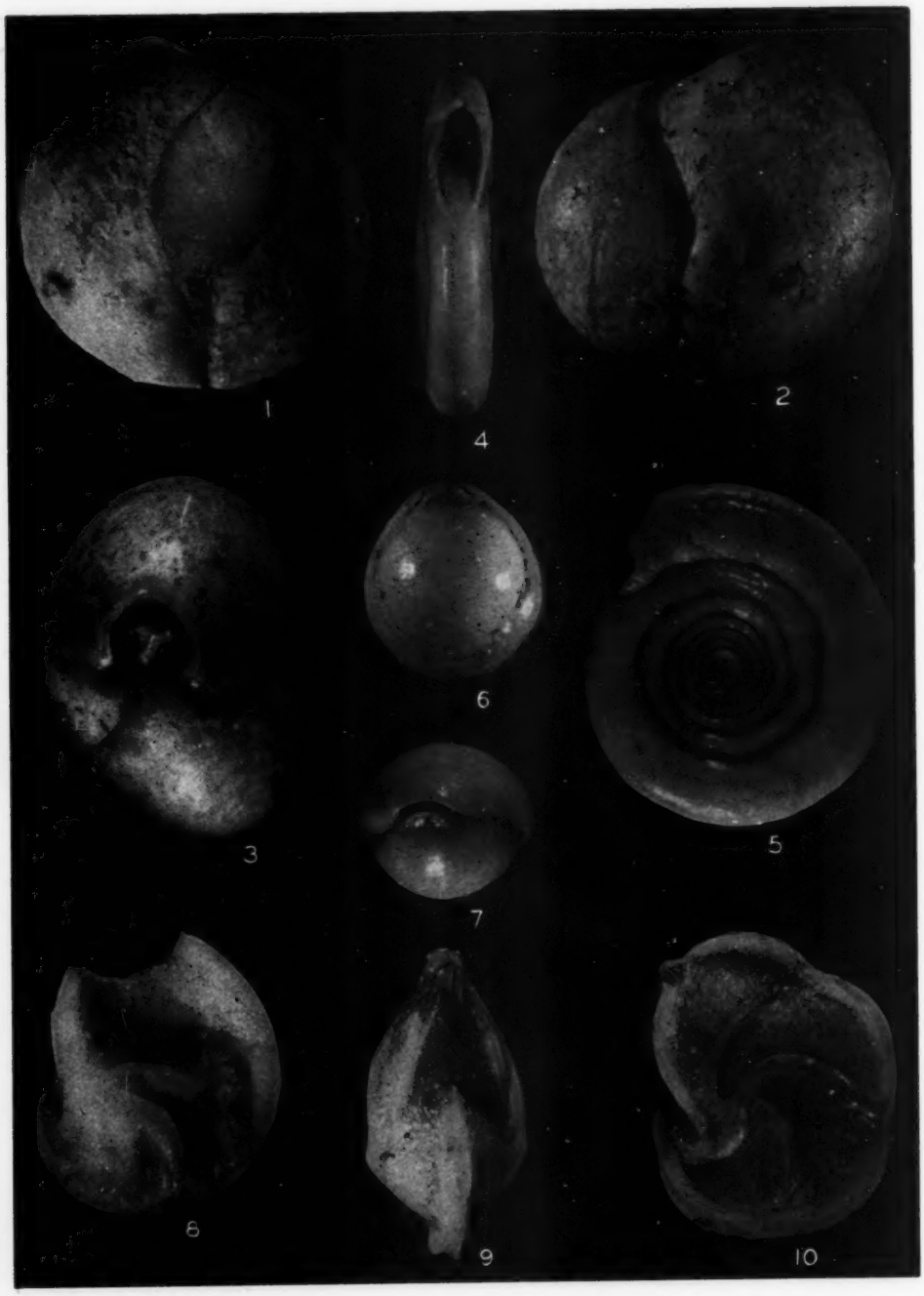
FIGS. *1, 2—Quinqueloculina* sp. *1*, Side view (four chambers). *2*, Side view (three chambers), ×40. (p. 594)

3, 4—Triloculina globosa (Hanna and Hanna). *3*, Side view (three chambers). *4*, Side view (two chambers). ×40. (p. 594)

5, 6—Massilina sp. a. *5*, Side view (five chambers). *6*, Side view (four chambers). ×40. (p. 594)

7–9—Triloculina? sp. a. *7*, Side view (three chambers). *8*, Side view (three chambers). *9*, Apertural view. ×40. (p. 594)

Beck, Eocene Foraminifera



Beck, Eocene Foraminifera

strongly convex; chambers three, inflated; sutures moderately distinct, strongly oblique to long axis; wall smooth; aperture radiate. Length, 0.62 mm.; breadth, 0.30 mm.; thickness, 0.20 mm.

Figured specimen.—No. 7467, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—The few specimens are variable and difficult to determine which is typical.

VAGINULINA? sp. B
Plate 106, figure 10

Test small, elongate, periphery broadly rounded, one margin nearly straight, other convex; chambers four, first three wider than high, last inflated, making up one-half of entire test; sutures distinct, moderately incised, oblique; wall smooth; aperture radiate. Length, 0.50 mm.; diameter, 0.20 mm.

Figured specimen.—No. 7468, Stanford Univ. Paleo. Type Coll., from station 8.

Remarks.—This single specimen is possibly a megalospheric *Dentalina*. Others are needed for certain generic identification.

Genus FRONDICULARIA Defrance, 1826
FRONDICULARIA VADERENSIS Beck, n. sp.
Plate 107, figure 18

Test large, much compressed, initial end somewhat rounded, apertural end pointed, periphery rounded; chambers 9, very narrow, elongate; early ones loosely coiled, later ones extending to base at either side; sutures distinct, flush with surface, curved; slightly hyaline; wall smooth; aperture indistinct. Length, 1.62 mm.; breadth, 0.58 mm.; thickness, 0.06 mm.

Holotype.—No. 7469, Stanford Univ. Paleo. Type Coll., from station 48.

Remarks.—This species shows affinity with *F. tenuissima* Hantken (1876) from the "*Clavulina szaboi*" beds of Hungary but Hantken's figure shows that the chamber arrangement and outline is different. *F. tenuissima* has been recorded by the following authors from the Western Hemisphere: Cushman (1927, p. 111, pl. 22, fig. 11), Nuttall (1935, p. 125, pl. 14, fig. 21) and Coryell and Embich (1937, p. 296, pl. 41, fig. 21). The figures in these publications indicate either that that species is a variable one, or that some of the identified specimens are not conspecific. Comparison of the Cowlitz specimens with these figures reveals sufficient difference to warrant describing them as a new species.

Genus LAGENA Walker and Jacob, 1798
LAGENA CONSCRIPTA Cushman and Barksdale
Plate 107, figure 38

Lagena isabella conscripta CUSHMAN and BARKSDALE, 1930, Stanford Univ. Dept. Geol. Contr., vol. 1, no. 2, p. 66, pl. 12, fig. 4.

Dimensions.—Length, 0.30 mm.; diameter, 0.20 mm.

Hypotype.—No. 7472, Stanford Univ. Paleo. Type Coll., from station 9.

Remarks.—The Cowlitz specimens are identical with those figured by Cushman and Barksdale (1930) from Martinez, California, but they differ from the original figure of *L. isabella* (d'Orbigny) in having a more fusiform test with the apertural end expanded.

LAGENA COSTATA (Williamson)
Plate 107, figure 36

Entosolenia costata WILLIAMSON, 1858, Recent Foraminifera of Great Britain, p. 9, pl. 1, fig. 18.

Dimensions.—Length, 0.30 mm.; diameter, 0.15 mm.

Hypotype.—No. 7470, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This species is rare in the material from Cowlitz River.

EXPLANATION OF PLATE 101

FIGS. *1–3*—*Triloculina gilboei* Beck, n. sp. *1*, Side view (three chambers). *2*, Side view (two chambers). *3*, Apertural view. Holotype, ×40. (p. 594)
4, 5—*Cornuspira lewisensis* Beck, n. sp. *4*, Apertural view. *5*, Side view. Holotype, ×40. (p. 594)
6, 7—*Biloculinella cowlitzensis* Beck, n. sp. *6*, Side view. *7*, Apertural view. Holotype, ×40. (p. 594)
8—*Lenticulina?* sp. a. ×40. (p. 597)
9, 10—*Robulus* sp. a. *9*, Peripheral view. *10*, Side view. ×30. (p. 596)

LAGENA HEXAGONA (Williamson)
Plate 107, figure 23

Entosolinia squamosa hexagona WILLIAMSON, 1848, Annals and Mag. Nat. History 2nd ser. vol. 1, p. 20, pl. 2, fig. 23.

Dimensions.—Length, 0.23 mm.; diameter, 0.20 mm.

Hypotype.—No. 7471, Stanford Univ. Paleo. Type Coll., from station 42.

Remarks.—A single specimen seems to be referable to the above species.

LAGENA cf. L. SEMISTRIATA Williamson
Plate 107, figure 32

Dimensions.—Length, 0.48 mm.; width, 0.16 mm.

Hypotype.—No. 7473, Stanford Univ. Paleo. Type Coll., from station 45.

Remarks.—The single specimen has not been compared with the original figure but, it resembles *L. semistriata* of Williamson of Cushman (1923, p. 26) from the Glendon limestone of Alabama.

LAGENA cf. L. SUBSTRIATA Williamson
Plate 107, figure 30

Dimensions.—Length, 0.28 mm.; diameter, 0.17 mm.

Hypotype.—No. 7474, Stanford Univ. Paleo. Type Coll., from station 8.

Remarks.—The specimens have not been compared with the original figure but they seem to be identical with *L. substriata* Laiming (1931).

LAGENA sp. A
Plate 107, figure 26

Dimensions.—Length, 0.33 mm.; diameter, 0.28 mm.

Figured specimen.—No. 7475, Stanford Univ. Paleo. Type Coll., from station 13.

Remarks.—This form has approximately 40 very fine striae crossing the test.

LAGENA? sp. B
Plate 107, figures 20, 37

Test large for the genus, longer than broad, subglobose; basal end with well-developed spine (broken from figured specimen); approximately 20 well-developed costae confined to lower one-half of test; wall heavy; aperture large. Length, 0.55 mm.; diameter, 0.45 mm.

Figured specimen.—No. 7476, Stanford Univ. Paleo. Type Coll., from station 26.

Remarks.—This form is similar to Cushman's *Lagena* sp.? (1939, p. 60, pl. 10, fig. 29) from submarine cores of the East Coast of North America.

Family POLYMORPHINIDAE
Genus GUTTULINA d'Orbigny, 1839
GUTTULINA IRREGULARIS (d'Orbigny)
Plate 106, figures 3, 15

Globulina irregularis D'ORBIGNY, 1846, Foram. Foss. Bass. Tert. Vienne, p. 226, pl. 13, figs. 9, 10.

Dimensions.—Length, 0.70 mm.; breadth, 0.58 mm.; thickness, 0.45 mm.

Hypotype.—No. 7477, Stanford Univ. Paleo. Type Coll., from station 9.

Remarks.—The Cowlitz specimens are variable but some seem identical with the original figure. The specimen figured here is close to *G. irregularis* (d'Orbigny) of Cushman and Ozawa (1930, pl. 3, figs. 4a, b, c) from the Miocene, Tortonian, *Amphistegina* marl, Nussdorf, near Vienna Austria.

For an extended synonomy and detailed discussion of this species see Cushman and Ozawa (1930, p. 25).

GUTTULINA PROBLEMA d'Orbigny
Plate 106, figures 11, 17, 20

Guttulina problema D'ORBIGNY, 1826, Annales Sci. Nat., vol. 7, p. 266, no. 14.

Dimensions.—1.10 mm.; breadth, 0.65 mm.; thickness, 0.41 mm.

Hypotype.—No. 7478, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This species was found in several samples but it is nowhere abundant. The figured specimen is close to a hypotype figured by Cushman and Ozawa (1930, pl. 3,

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EXPLANATION OF PLATE 102

FIGS. *1, 7—Robulus kincaidi* Beck, n. sp. *1*, Side view. *7*, Peripheral view. Holotype, ×60. (p. 595)
2, 3—Robulus sp. b. *2*, Side view. *3*, Apertural view. ×45. (p. 596)
4, 8—Robulus welchi Church. *4*, Side view. *8*, Apertural view. ×60. (p. 596)
5, 6—Robulus? sp. d. *5*, Apertural view. *6*, Side view. ×30. (p. 596)

Beck, Eocene Foraminifera

Beck, Eocene Foraminifera

fig. 1) in whose paper are an extended synonomy and additional occurrences.

GUTTULINA sp. A
Plate 107, figure 27

Dimensions.—Length, 0.32 mm.; breadth, 0.18 mm.; thickness, 0.10 mm.

Figured specimen.—No. 7479, Stanford Univ. Paleo. Type Coll., from station 46.

Remarks.—The single specimen is not well enough preserved for specific determination.

GUTTULINA? sp. B
Plate 107, figure 35

Dimensions.—Length, 0.42 mm.; breadth, 0.20 mm.; thickness, 0.13 mm.

Figured specimen.—No. 7480, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—The chamber arrangement of the single specimen is not clear but, it is believed to belong to the above genus.

Genus GLOBULINA d'Orbigny
GLOBULINA LANDESI (Hanna and Hanna) Cushman and Ozawa
Plate 106, figures 14, 16

Polymorphina landesi HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geol., vol. 1, no. 4, p. 60, pl. 13, figs. 16, 17.

Dimensions.—Length, 0.45 mm.; breadth, 0.45 mm.; thickness, 0.38 mm.

Hypotype.—No. 7481, Stanford Univ. Paleo. Type Coll., from station 17.

Remarks.—This species occurs in most samples. It has been recorded by Cushman and Dusenbury (1934, p. 59, pl. 8, figs. 1, 3) from the Poway conglomerate of the La Jolla quadrangle, California.

GLOBULINA MINUTA SINUATA Beck, n. subsp.
Plate 106, figure 13

Dimensions.—Length, 0.35 mm.; breadth, 0.18 mm.; thickness, 0.16 mm.

Holotype.—No. 7482, Stanford Univ. Paleo. Type Coll., from station 13.

Remarks.—This subspecies differs from the typical form in having slightly incised and sinuate sutures. Specimens are rare but enough are present to show that these suture characteristics are typical.

Genus GLANDULINA d'Orbigny, 1826
GLANDULINA LAEVIGATA d'Orbigny
Plate 107, figures 4, 5

Nodosaria (Glandulina) laevigata D'ORBIGNY, 1826, Annales Sci. Nat., vol. 7, p. 252, no. 1, pl. 10, figs. 1–3.

Dimensions.—Length, 0.62 mm.; diameter, 0.41 mm.

Hypotype.—No. 7483, Stanford Univ. Paleo. Type Coll., from station 51.

Remarks.—Very few specimens have been found.

Genus SIGMOMORPHINA Cushman and Ozawa, 1928
SIGMOMORPHINA sp. A
Plate 106, figures 6, 8

Dimensions.—Length, 0.33 mm.; breadth, 0.21 mm.; thickness, 0.09 mm.

Figured specimen.—No. 7484, Stanford Univ. Paleo. Type Coll., from station 55.

Remarks.—Only a single specimen has been found.

Family NONIONIDAE
Genus NONION Montfort, 1808
NONION PLANATUM Cushman and Thomas
Plate 107, figures 12, 13

Nonion planatum CUSHMAN and THOMAS, 1930, Jour. Paleontology, vol. 4, p. 37, pl. 3, figs. 5a, b.

Dimensions.—Diameter, 0.37 mm.; thickness, 0.18 mm.

Hypotype.—No. 7485, Stanford Univ. Type Coll., from station 24.

Remarks.—This species is common in the type Cowlitz formation and also occurs in collections from the type Tejon and Eocene Kreyenhagen formations of California, and

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EXPLANATION OF PLATE 103

FIGS. *1, 2, 4, 5—Robulus texanus* (Cushman and Applin). Two different specimens. *1*, Side view of a large form that is in the early stage of uncoiling. *2*, Side view of a specimen that is in the latter stage of uncoiling. *4*, Apertural view of *1*. *5*, Apertural view of *2*, ×40. (p. 595)

3, 8—Robulus weaveri Beck, n. sp. *3*, Apertural view showing the asymmetrical apertural face. *8*, Side view. Holotype, ×40. (p. 595)

6, 7—Robulus sp. c. *6*, Side view. *7*, Apertural view, ×45. (p. 596)

the Bassendorf and Coaledo formations of Oregon. It has been recorded by Cushman and Dusenbury (1934, p. 60) from the Poway conglomerate of La Jolla quadrangle, California.

NONION INFLATUM Cushman and Ellisor
Plate 107, figures 14, 15

Nonion scaphum inflatum CUSHMAN and ELLISOR, 1932, Cushman Lab. Foram. Research Contr., vol. 8, pt. 2, p. 41, pl. 6, figs. 2a, b.

Dimensions.—Length, 0.50 mm.; breadth, 0.40 mm.; thickness, 0.22 mm.

Hypotype.—No. 7486, Stanford Univ. Paleo. Type Coll., from station 4.

Remarks.—The Cowlitz specimens are longer than the form figured by Cushman and Ellisor (1932) who state, however, that some of their specimens from the type locality are also longer. Comparison with the original figure of *Nonion scaphum* (Fichtel and Moll) shows the Cowlitz form to differ in being less compressed and in having fewer, narrower chambers, a more rounded periphery, and a lower and wider apertural face. It is considered to be a distinct species.

Genus BOLIVINOPSIS Yakovlev, 1891
BOLIVINOPSIS? sp. A
Plate 107, figures 2, 8

Dimensions.—Length, 0.57 mm.; width, 0.15 mm.; thickness, 0.07 mm.

Figured specimen.—No. 7487, Stanford Univ. Paleo. Type Coll., from station 26.

Remarks.—The generic position of this single specimen is doubtful and it is possibly an aberrant *Bolivina*.

Family BULIMINIDAE
Genus ROBERTINA d'Orbigny, 1846
ROBERTINA DECLIVIS (Reuss) 1864
Plate 107, figures 1, 7, 25

Bulimina declivis REUSS, 1863 (1864), Sitz. Wiss. Wien., vol. 48, pt. 1, p. 55, pl. 6, figs. 70a, b; pl. 7, fig. 71.

Dimensions.—Length, 35–57 mm.; breadth, 20–33 mm.

Hypotype.—No. 7488, Stanford Univ. Paleo. Type Coll., from station 18.

Remarks.—The two figured specimens agree closely with the specimens figured by Reuss from the Oligocene of Offenbach, Germany. The Cowlitz River specimens vary in size, but the ratio of length to breadth is constant and it is the same as that of the original figures. The arrangement of their chambers and the size and angle of their apertures are also identical.

ROBERTINA WASHINGTONENSIS Beck, n. sp.
Plate 107, figures 17, 19, 24

Test nearly three times as long as broad, initial end sharply pointed, evenly tapering, fusiform, greatest breadth slightly above middle; chambers slightly inflated; 5 pairs in adult whorl, increasing in size as added; sutures moderately depressed; wall smooth, very finely perforate; aperture narrow, comma-shaped, extending about two-thirds of way across apertural face, slightly oblique to vertical axis of test, supplementary aperture indistinct. Length, 0.57 mm.; breadth, 0.20 mm.

Holotype.—No. 7489, Stanford Univ. Paleo. Type Coll., from station 43.

EXPLANATION OF PLATE 104

FIGS. *1–4, 10, 14—Robulus inornatus* (d'Orbigny). Three different specimens. *1*, Side view. *2*, Apertural view of *1*. *3*, Apertural view of typical specimen. *4*, Side view of *3*. *10*, Side view. *14*, Apertural view of *10*. ×40. (p. 595)

5, 9—Lenticulina convergens (Bornemann). *5*, Side view. *9*, Apertural view, ×45. (p. 596)

6, 12—Robulus propinquus cowlitzensis Beck, n. subsp. *6*, Side view. *12*, Apertural view. Holotype, ×60. (p. 595)

7—Marginulina cf. *M. subbullata* Hantken, ×40. (p. 597)

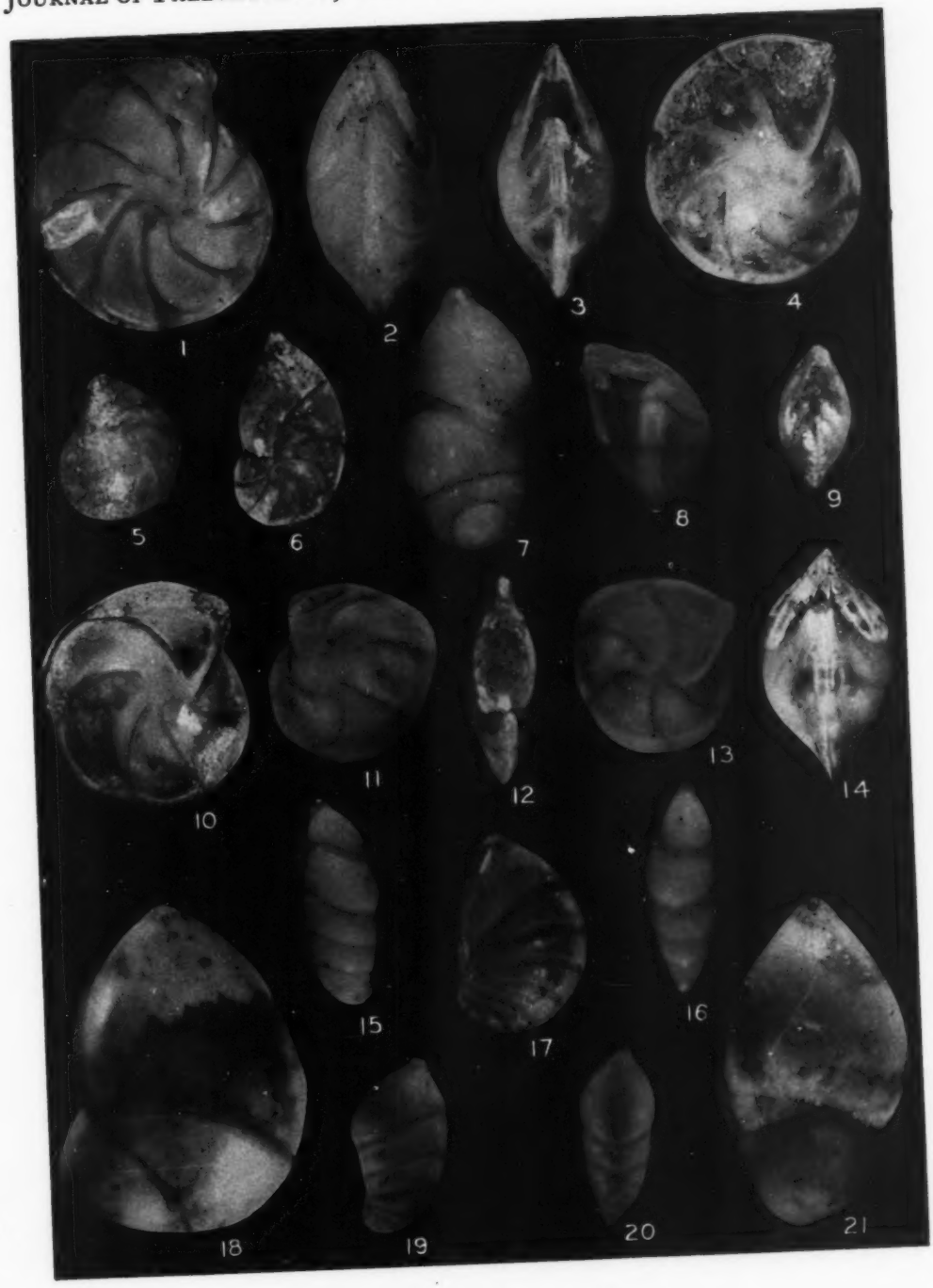
8, 11, 13—Darbyella? sp. a. *8*, Apertural view. *11, 13*, Side views, ×40. (p. 596)

15, 16—Marginulina eximia Neugeboren. *15*, Side view. *16*, Edge view, ×40. (p. 597)

17—Astacolus barksdalei Beck, n. sp. Holotype, ×40. (p. 597)

18, 21—Lenticulina washingtonensis Beck, n. sp. *18*, Side view. *21*, Apertural view. Holotype, ×45. (p. 597)

19, 20—Marginulina sp. a. *19*, Side view. *20*, Edge view, ×40. (p. 597)



Beck, Eocene Foraminifera

Beck, Eocene Foraminifera

Remarks.—The general shape and chamber arrangement of this species is similar to *R. wilcoxensis* Cushman and Ponton (1932, p. 66, pl. 8, figs. 19 a, b) except that it is narrower. Its aperture, however, is more than twice as long, and is curved, and oblique to the long axis of the test.

Genus BULIMINA d'Orbigny, 1826
BULIMINA CUNEATA Cushman
Plate 107, figures 3, 9

Bulimina jacksonensis CUSHMAN var. *cuneata* CUSHMAN, 1926, Cushman Lab. Foram. Research Contr., vol. 2, p. 35. (Figured by CUSHMAN, 1935, U. S. Geol. Survey Prof. Paper 181, pl. 13, figs. 10, 11.)

Dimensions.—Length, 0.68 mm.; breadth, 0.38 mm.

Hypotype.—No. 7490, Stanford Univ. Paleo. Type Coll., from station 46.

Remarks.—This species is rather rare at Cowlitz River and it shows considerable variation in the degree of serration and number (9–13) of the platelike costae. The figured specimen is less tenuate than some others occurring in the same sample but some specimens are identical with Cushman's (1935) figure of *Bulimina jacksonensis cuneata.*

The Cowlitz form differs from *B. jacksonensis* Cushman (1925) in having a more tapering test, and a greater number of costae that are serrate and platelike. It differs from *B. sculptilis* Cushman of Cushman and Schenck (1928) in being smaller and having a greater number of platelike costae. Similar specimens are known from the type Tejon formation of California.

BULIMINA OVATA COWLITZENSIS Beck, n. subsp.
Plate 107, figure 22

Dimensions.—Length, 0.45 mm.; diameter, 0.25 mm.

Holotype.—No. 7491, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This subspecies differs from the typical form in having more inflated chambers, and a coarsely punctate wall.

Genus BULIMINA d'Orbigny, 1826
BULIMINA SCHENCKI Beck, n. sp.
Plate 107, figures 28, 33

Test small, about twice as long as broad, fusiform, greatest width through middle, initial end subacute; chambers few, last three make up more than one-half of entire test, inflated; sutures distinct, deeply incised; wall smooth; aperture set in broad opening at top of last chamber. Length, 0.33 mm.; diameter, 0.18 mm.

Holotype.—No. 7492, Stanford Univ. Paleo. Type Coll., from station 2.

Remarks.—These specimens are identical with *Bulimina capitata?* of Cushman and Dusenbury (1934) and differ from the original figure of *B. capitata* Yokoyama (1890) in having less inflated chambers that are largest at the apertural end.

EXPLANATION OF PLATE 105

FIGS. *1, 2, 4, 5, 10—Vaginulinopsis saundersi* (Hanna and Hanna). Three different specimens. *1,* Side view. *2,* Peripheral view. *4,* Peripheral view of *1. 5,* Side view of *2. 10,* Side view of an elongate form, ×40. (p. 598)

3, 13—Vaginulinopsis saundersi (Hanna and Hanna) subspecies *lewisensis* Beck, n. subsp. *3,* side view. *13,* Peripheral view. Holotype, ×40. (p. 598)

6, 7—Marginulina sp. B. *6,* Side view. *7,* Edge view, ×40. (p. 598)

8—Nodosaria sp. a., ×40. (p. 599)

9—Dentalina? sp. b., ×40. (p. 599)

11, 17—Dentalina sp. a. *11,* Side view. *17,* Apertural view, ×40. (p. 599)

12—Pseudoglandulina conica (Neugeboren). ×40. (p. 599)

14—Dentalina cf. *D. dusenburyi* Beck. ×40. (p. 599)

15, 16—Marginulina sp. c. *15,* Side view. *16.* Edge view, ×40. (p. 598)

18—Dentalina colei Cushman and Dusenbury, ×40. (p. 598)

19, 21—Nodosaria cf. *N. pyrula* d'Orbigny. Two different specimens. *19,* Single apertural chamber. *21,* Specimen showing part of an additional chamber, ×40. (p. 599)

20, 23—Dentalina dusenburyi Beck, n. sp. Two different specimens. *20,* Immature form. *23,* Large incomplete specimen, holotype, ×40. (p. 599)

22—Dentalina communis (d'Orbigny), ×40. (p. 598)

Genus GLOBOBULIMINA Cushman, 1927
GLOBOBULIMINA PACIFICA Cushman
Plate 107, figure 16

Globobulimina pacifica CUSHMAN, 1927, Cushman Lab. Foram. Research Contr., vol. 3, p. 67, pl. 14, fig. 12.

Dimensions.—Length, 0.57 mm.; breadth, 0.36 mm.

Hypotype.—No. 7493, Stanford Univ. Paleo. Type Coll., from station 4.

Remarks.—This very wide spread and long ranging species is common at Cowlitz River. For an extended synonomy see Kleinpell (1938, p. 260).

Genus ENTOSOLENIA Ehrenberg, 1848
ENTOSOLENIA? sp. A
Plate 107, figures 29, 31

Dimensions.—Length, 0.38 mm.; breadth, 0.30 mm.

Figured specimen.—No. 7494, Stanford Univ. Paleo. Type Coll., from station 12.

Remarks.—Specimens of their form are very rare and difficult to identify generically. They seem to be related to *Entosolenia* except for their radiate apertures.

Genus VIRGULINA d'Orbigny, 1826
VIRGULINA HOBSONI Beck, n. sp.
Plate 107, figures 6, 10

Test elongate, more than three times as long as broad, compressed, broadest near apertural end, ends and margins broadly rounded; approximately 8 chambers of irregular shape, early ones seemingly triserial, later ones becoming irregularly biserial, last two inflated; sutures moderately depressed; wall smooth, very finely perforate; aperture a curved loop, situated on inner face of final chamber. Length, 0.50 mm.; width, 0.17 mm.; thickness, 0.15 mm.

Holotype.—No. 7495, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—In some respects this species resembles *Virgulina punctata* d'Orbigny of Cushman (1932) but differs in the early chamber arrangement and the character of the initial end, which is broadly rounded, rather than bluntly pointed.

Genus BOLIVINA d'Orbigny, 1839
BOLIVINA HUNERI Howe
Plate 107, figure 21

Bolivina huneri HOWE, 1939, Louisiana Dept. Conserv. Geol. Bull. no. 14, p. 66, pl. 9, figures 3, 4.

Dimensions.—Length, 0.27 mm.; breadth, 0.14 mm.; thickness, 0.08 mm.

Hypotype.—No. 7496, Stanford Univ. Paleo. Type Coll., from station 47.

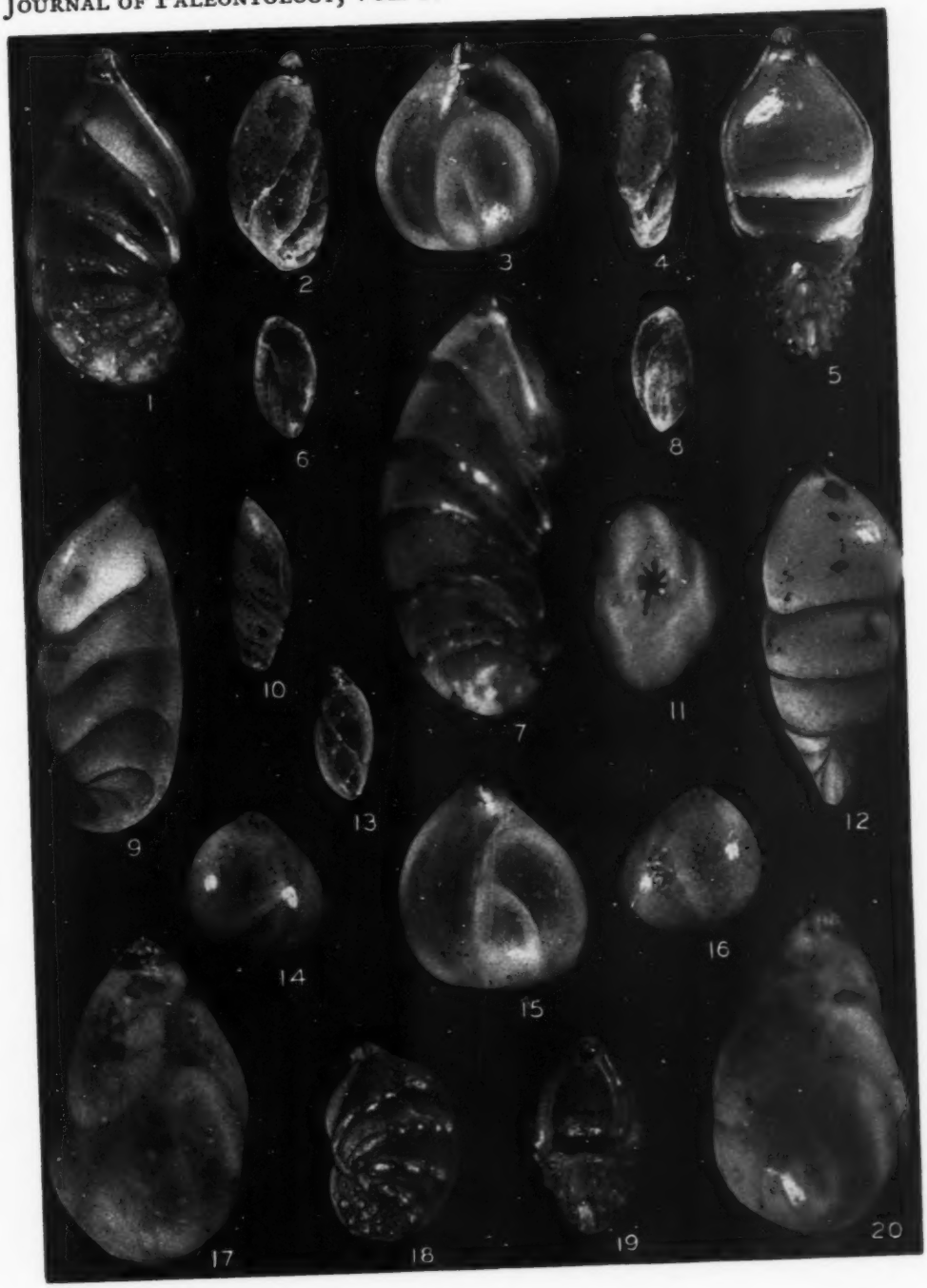
Remarks.—The Cowlitz specimens seem to be identical with the delicate, distinctive Cook Mountain species. The figured specimen is shorter than the specimen figured by Howe but others approach the dimension of the Cook Mountain forms.

BOLIVINA KLEINPELLI Beck, n. sp
Plate 107, figure 39

Test moderately small, compressed, slightly tapering from semiacute initial end, generally twisted, periphery sharp; chambers numerous, gradually becoming larger toward apertural end; sutures distinct, flush with surface, hyaline, typically sinuous but variable; wall thin, translucent, finely perforate; aperture an elongate slit. Length, 0.55 mm.; breadth, 0.20 mm.; thickness, 0.09 mm.

EXPLANATION OF PLATE 106

FIGS. *1, 5, 7—Saracenaria mackini* Beck, n. sp. *1*, Side view of holotype. *5*, Apertural view of *1*. *7*, Side view of a paratype, ×40. (p. 600)
2, 4—Vaginulina sp. a., ×40. (p. 600)
3, 15—Guttulina irregularis (d'Orbigny), ×40. (p. 602)
6, 8—Sigmomorphina sp. a., ×40. (p. 603)
9, 12—Saracenaria hanikeni Cushman. *9*, Side view. *12*. Edge view, ×40. (p. 600)
10—Vaginulina? sp. b., ×40. (p. 601)
11, 17, 20—Guttulina problema d'Orbigny. *11*, Apertural view. *17, 20*, Side views, ×40. (p. 602)
13—Globulina minuta sinuata Beck, n. subsp. Holotype, ×40. (p. 603)
14, 16—Globulina landesi (Hanna and Hanna), ×45. (p. 603)
18, 19—Saracenaria mackini Beck subspecies *cowlitzensis* Beck, n. subsp. *18*, Side view. *19*, Apertural view. Holotype, ×40. (p. 600)



Beck, Eocene Foraminifera

Beck, Eocene Foraminifera

Holotype.—No. 7497, Stanford Univ. Paleo. Type Coll., from station 59.

Remarks.—This distinctive species resembles *B. gardnerae* Cushman (1926, p. 31) but differs in being larger, and having a more acute initial end and sinuous sutures.

BOLIVINA? sp. A
Plate 107, figure 11

Dimensions.—Length, 0.25+ mm.; breadth, 0.16+ mm.; thickness, 0.08 mm.

Figured specimen.—No. 7498, Stanford Univ. Paleo. Type Coll., from station 47.

Remarks.—A single broken specimen possesses a well-preserved initial end similar to that of *Bolivina louisiana* Howe (1939) from the Cook Mountain Eocene. Complete specimens are necessary, however, for identification.

Genus UVIGERINA d'Orbigny, 1826
UVIGERINA cf. U. CHURCHI Cushman and Siegfus
Plate 108, figure 30

Dimensions.—Length, 0.35 mm.; diameter, 0.20 mm.

Hypotype.—No. 7499, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—A single specimen resembles some variants of the original figure and topotypes of *U. churchi* Cushman and Siegfus (1939) but differs from the holotype in having fewer, lower costae and a longer neck. Other specimens which may be conspecific with the Cowlitz form have been collected from the Tejon formation, at the south end of San Joaquin Valley, Kern County, California.

Genus ANGULOGERINA Cushman, 1927
ANGULOGERINA HANNAI Beck, n. sp.
Plate 108, figures 26, 28.

Test small, elongate, nearly three times as long as broad, sides nearly parallel, triangular in cross section, periphery subacute; chambers distinct, slightly inflated; sutures distinct, deeply incised, curved; wall smooth, perforate; aperture terminal, with slight lip. Length, 0.45 mm.; diameter, 0.18 mm.

Holotype.—No. 7500, Stanford Univ. Paleo. Type Coll., from station 18.

Remarks.—This distinctive species re-

EXPLANATION OF PLATE 107

FIGS. *1, 7, 25—Robertina declivis* (Reuss). Two different specimens. *1*, Apertural view. *7*, Side view of *1*. *25*, Immature specimen, ×40. (p. 604)
2, 8—Bolivinopsis? sp. a. *2*, Apertural view. *8*, Side view, ×45. (p. 604)
3, 9—Bulimina cuneata Cushman. *3*, Side view. *9*, Apertural view, ×45. (p. 605)
4, 5—Glandulina laevigata d'Orbigny. *4*, Apertural view. *5*, Side view, ×45. (p. 603)
6, 10—Virgulina hobsoni Beck, n. sp. *6*, Apertural view. *10*, Side view. Holotype, ×40. (p. 606)
11—Bolivina? sp. a., ×40. (p. 607)
12, 13—Nonion planatum Cushman and Thomas. *12*, Side view. *13*, Apertural view, ×45. (p. 603)
14, 15—Nonion inflatum Cushman and Ellisor. *14*, Side view. *15*, Apertural view. ×40 (p. 604)
16—Globobulimina pacifica Cushman, ×45. (p. 606)
17, 19, 24—Robertina washingtonensis Beck, n. sp. *17*, Side view of holotype. *19*, Apertural view of *17*. *24*, Paratype, ×40. (p. 604)
18—Frondicularia vaderensis Beck, n. sp. Holotype, ×45. (p. 601)
20, 37—Lagena? sp. b. *20*, Apertural view. *37*, Side view, ×40. (p. 602)
21—Bolivina huneri Howe, ×75. (p. 606)
22—Bulimina ovata cowlitzensis Beck, n. subsp. Holotype, ×40. (p. 605)
23—Lagena hexagona (Williamson) ×40. (p. 602)
26—Lagena sp. a., ×40. (p. 602)
27—Guttulina sp. a., ×60. (p. 603)
28, 33—Bulimina schencki Beck, n. sp. Holotype, ×60. (p. 605)
29, 31—Entosolenia? sp. a. *29*, Side view. *31*, Apertural view, ×45. (p. 606)
30—Lagena cf. *L. substriata* Williamson, ×75. (p. 602)
32—Lagena cf. *L. semistriata* Williamson, ×50. (p. 602)
34—Vaginulina cf. *V. wrighti* Cole, ×40. (p. 600)
35—Guttulina? sp. b, ×50. (p. 603)
36—Lagena costata (Williamson), ×45. (p. 601)
38—Lagena conscripta Cushman and Barksdale, ×45. (p. 601)
39—Bolivina kleinpelli Beck, n. sp. Holotype, ×50. (p. 606)

sembles *A. wilcoxensis* (Cushman and Ponton 1939), but differs in being longer, and lacking the two distinct ribs on the angles, with an intervening channel.

Family ELLIPSOIDINIDAE
Genus ELLIPSONODOSARIA A. Silvestri, 1900
ELLIPSONODOSARIA cf. E. COCOAENSIS (Cushman)
Plate 108, figure 10

Nodosaria sp. CUSHMAN and APPLIN, 1926, Am. Assoc. Petroleum Geologists Bull. vol. 10, p. 170, pl. 7, fig. 17.

Dimensions.—Length, 1.22+ mm.; diameter, 0.18 mm.

Hypotype.—No. 7501, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—A single broken specimen resembles figures of *E. cocoaensis* of Cushman, (1939, p. 68, pl. 11, figs. 27–33) from a submarine core off the eastern coast of North America. Cushman (1939) discussed the similarity between his specimens and Nuttall's *E. verneuillii* (d'Orbigny) from Venezuela. The Cowlitz specimen is also similar to that species.

Family ROTALIIDAE
Genus VALVULINERIA Cushman, 1926
VALVULINERIA cf. V. SCROBICULATA (Schwager)
Plate 108, figures 21–23

Dimensions.—Diameter, 0.45 mm.; breadth, 0.30 mm.

Hypotype.—No. 7502, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—A few specimens resemble the original figures of *V. scrobiculata* (Schwager, 1883) but are more similar to specimens identified as that species by Cushman and Ponton (1932, p. 70, pl. 9, figs. 5 a–c) from the Wilcox near Ozark, Alabama.

Genus EPONIDES Montfort, 1808
EPONIDES CONDONI Cushman and Schenck
Plate 108, figures 27, 29, 31

Eponides condoni CUSHMAN and SCHENCK, 1928, California Univ. Dept. Geol. Sci. Bull. vol. 17, no. 9, p. 313, pl. 44, figs. 6, 7a, b, c.

Dimensions.—Diameter, 0.30 mm.; thickness, 0.18 mm.

Hypotype.—No. 7503, Stanford Univ. Paleo. Type Coll., from station 13.

Remarks.—Rare specimens are identical with topotypes from the Bassendorf formation except that they are slightly smaller. The Cowlitz specimens are probably immature.

EPONIDES MINIMUS Cushman
Plate 108, figures 16, 17, 19

Eponides minima CUSHMAN, 1933, Cushman Lab. Foram. Research Contr., vol. 9, pt. 1, p. 17, pl. 2, figs. 8a, b, c.

Dimensions.—Length, 0.30 mm.; thickness, 0.18 mm.

Hypotype.—No. 7504, Stanford Univ. Paleo. Type Coll., from station 8.

Remarks.—The Cowlitz specimens are identical with those figured by Cushman from the upper Eocene, Cooper marl, of South Carolina.

EPONIDES YEGUAENSIS Weinzierl and Applin
Plate 108, figures 1, 4

Eponides guayabalensis COLE var. *yeguaensis* WEINZIERL and APPLIN, 1929, Jour. Paleontology, vol. 3, p. 406, pl. 42, figs. 2a–c.
Truncatulina praecincta? HANNA and HANNA, 1924, Washington Univ. [Seattle] Pub. in Geology, vol. 1, no. 4, p. 59, pl. 13, figs. 11, 12.
Eponides yeguaensis CUSHMAN and MCMASTERS, 1936, Jour. Paleontology, vol. 10, no. 6, p. 514, pl. 76, figs. 1a–c.

Dimensions.—Length, 0.98 mm.; thickness, 0.50 mm.

Hypotype.—No. 7505, Stanford Univ. Paleo. Type Coll., from station 27.

Remarks.—The figured specimen is conspecific with topotypes of *Eponides yeguaensis* Weinzierl and Applin of Cushman and McMasters from the Llajas formation of California with which it has been compared. Cushman and McMasters (1936, p. 514) compared their specimens with the holotype. J. A. Cushman has written (1943) that at present he considers this form to be a variety.

Genus SIPHONINA Reuss 1849
SIPHONINA CLAIBORNENSIS COWLITZENSIS Beck, n. subsp.
Plate 108, figures 15, 18

Dimensions.—Diameter, 0.50 mm.; thickness, 0.25 mm.

Holotype.—No. 7506, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—This subspecies differs from the typical form in having a less elongate aperture with a distinct neck.

Family CASSIDULINIDAE
Genus CERATOBULIMINA Toula, 1915
CERATOBULIMINA WASHBURNEI Cushman and Schenck
Plate 108, figures 20, 24

Ceratobulimina washburnei CUSHMAN and SCHENCK, 1928, California Univ. Dept. Geol. Sci. Bull., vol. 17, no. 9, p. 314, pl. 45, figs. 1a, b, c.

Dimensions.—Height, 0.60 mm.; breadth, 0.47 mm.; thickness, 0.30 mm.

Hypotype.—No. 7507, Stanford Univ. Paleo Type Coll., from station 26.

Remarks.—The Cowlitz specimens seem to be identical with those from the Keasey formation. The figured specimen is higher and thinner than the holotype but, others agree with its dimensions.

Genus CASSIDULINA d'Orbigny, 1826
CASSIDULINA GLOBOSA Hantken
Plate 108, figures 7, 13, 14

Cassidulina globosa HANTKEN, 1875 (1876), Magy. kir. foldt, int. Evkönyve, vol. 4, p. 54, pl. 16, fig. 2.

Dimensions.—Height, 0.33 mm.; breadth, 0.25 mm.; thickness, 0.20 mm.

Hypotype.—No. 7508, Stanford Univ. Paleo. Type Coll., from station 46.

Remarks.—This species is common in the Eocene of Washington, Oregon and California.

Family CHILOSTOMELLIDAE
Genus PULLENIA Parker and Jones, 1862
PULLENIA SALISBURYI Stewart and Stewart
Plate 108, figures 8, 12

Pullenia salisburyi STEWART and STEWART, 1930, Jour. Paleontology, vol. 4, p. 72, pl. 8, figs. 2a, b.

Dimensions.—Height, 0.40 mm.; breadth, 0.30 mm.; thickness, 0.20 mm.

Hypotype.—No. 7509, Stanford Univ. Paleo. Type Coll., from station 47.

Remarks.—The Cowlitz River specimens seem to be identical with the holotype described from the Pico formation (Pliocene) of California, thus indicating a long range for the species.

The peripheral outline, chamber arrangement, and sutures of *Nonion* cf. *N. applini* Cushman and McMasters (1936, p. 513, pl. 75, fig. 16) are the same as those of the Cowlitz specimens and it is possible that they are conspecific.

PULLENIA? sp. a
Plate 108, figures 5, 6

Dimensions.—Diameter, 0.55 mm.; thickness, 0.32 mm.

Figured specimen.—No. 7510 Stanford Univ. Paleo. Type Coll., from collecting station 58.

Remarks.—A single imperfect specimen has been found.

Family GLOBIGERINIDAE
Genus GLOBIGERINA d'Orbigny, 1826
GLOBIGERINA TRILOCULINOIDES Plummer
Plate 108, figures 2, 3

Globigerina triloculinoides PLUMMER, 1927, Texas Univ. Bull. 2644, p. 134, pl. 8, figs. 10a, b, c.

Dimensions.—Diameter, 0.35 mm.; thickness. 0.28 mm.

Hypotype.—No. 7511, Stanford Univ. Type. Coll., from station 8.

Remarks.—This species is common and variable. See Toulmin (1941, p. 607–608) for extended synonomy, and additional occurrences of this species.

Genus ORBULINA d'Orbigny, 1839
ORBULINA UNIVERSA d'Orbigny
Plate 108, figure 25

Orbulina universa D'ORBIGNY, 1839, Hist. Phys. Pol. Nat. Cuba, vol. 2, Zool., p. 3, pl. 1, fig. 1.

Dimensions.—Diameter, 0.30 mm.

Hypotype.—No. 7512, Stanford Univ. Paleo. Type Coll., from station 12.

Remarks.—This species is common but it is not represented in any sample by a great number of specimens. The aperture is obscured on all observed specimens. Coryell and Mossman (1942, p. 239) describe this species from the Pliocene of Panama and also note that the aperture is not clearly defined.

Family ANOMALINIDAE
Genus ANOMALINA d'Orbigny, 1826
ANOMALINA COSTIANA Weinzierl and Applin
Plate 109, figures 12, 19, 23

Anomalina costiana WEINZIERL and APPLIN, 1929, Jour. Paleontology, vol. 3, p. 409, pl. 44, figs. 7a, b, c.

Test small, biconvex, dorsal side of adult

completely involute with plug of clear shell material filling umbilicus, ventral side slightly evolute, showing previous coils through clear shell material, periphery semiacute in earlier coiled portion, becoming rounded toward latter part; chambers distinct, usually 12 in last whorl, slight increase in height and width as added; sutures distinct, hyaline, slightly limbate, early ones flush with surface, latter ones incised, curved backward, last gradually straightening forward upon crossing periphery; wall polished, coarsely perforate; aperture peripheral. Length, 0.46 mm.; breadth, 0.36 mm.; thickness, 0.12 mm.

Hypotype.—No. 7513, Stanford Univ. Paleo. Type Coll., from station 49.

Remarks.—A small undescribed form from the Tejon formation of California may be a variety of the above species; it differs in having more limbation of the sutures and it is completely involute. *A. affinis* (Hantken)? of Cushman and Dusenbury (1934, p. 64) and *Cibicides* sp. Cushman and Garret (1939, p. 88) resemble the Cowlitz River specimens but they differ in having fewer chambers.

ANOMALINA sp. A
Plate 108, figures 9, 11

Test small, dorsal side evolute, ventral side completely involute with very moderate depression at umbilicus, periphery broadly rounded; chambers distinct, shape and size rather uniform, usually eight in last coil, all visible from dorsal side; sutures distinct, flush with surface, curved backward; wall smooth, polished; aperture small, at base of last chamber in median line. Height, 0.28 mm.; breadth, 0.20 mm.; thickness, 0.14 mm.

Figured specimen.—No. 7514, Stanford Paleo. Type Coll., from station 40.

Remarks.—This small, rare form resembles immature specimens of *A. garzaensis* Cushman and Siegfus; (1939) but specimens are too few to permit satisfactory identification.

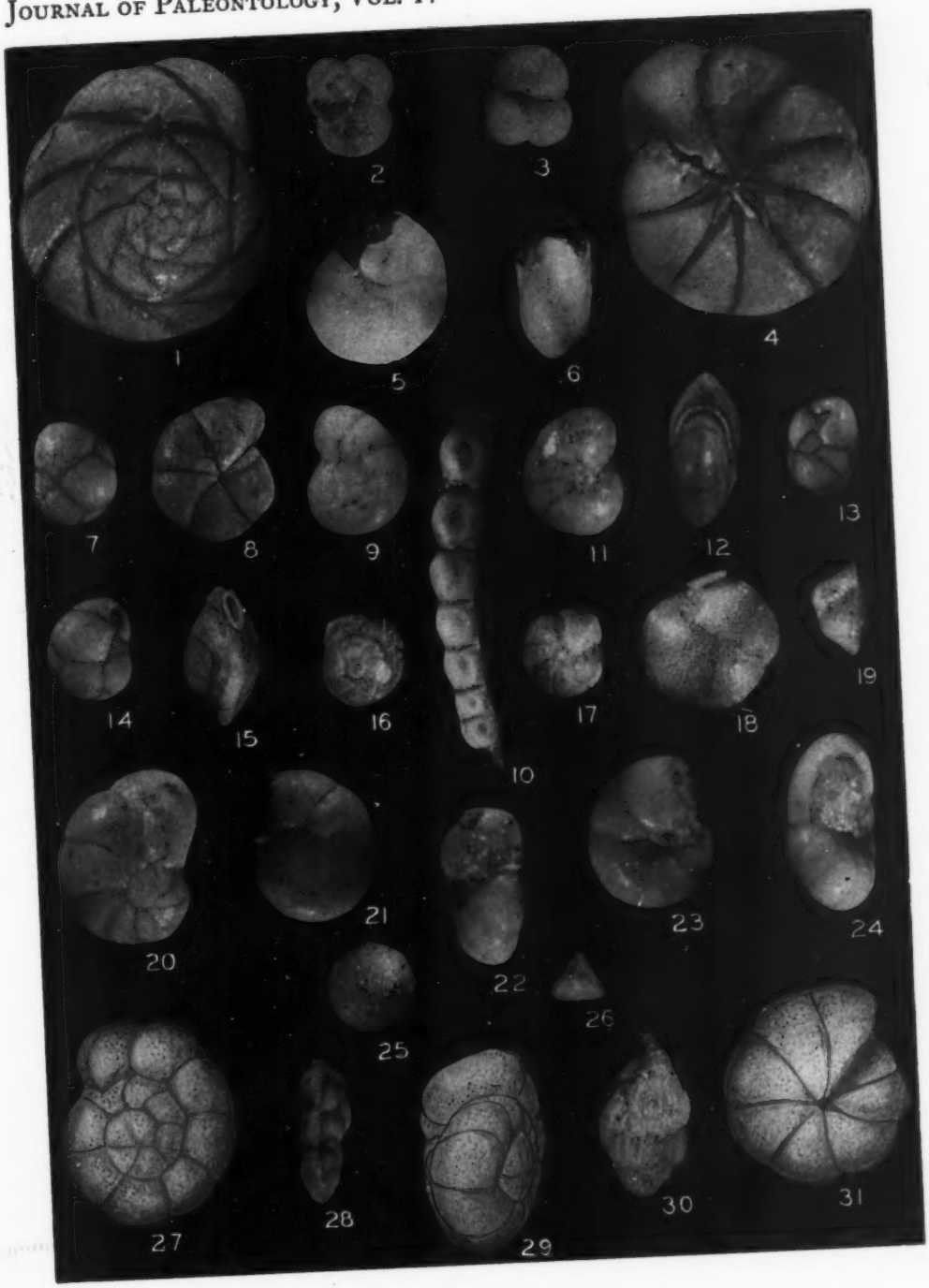
ANOMALINA? sp. B
Plate 109, figures 6, 10, 14

Dimensions.—Height, 0.28 mm.; breadth, 0.20 mm.; thickness, 0.08 mm.

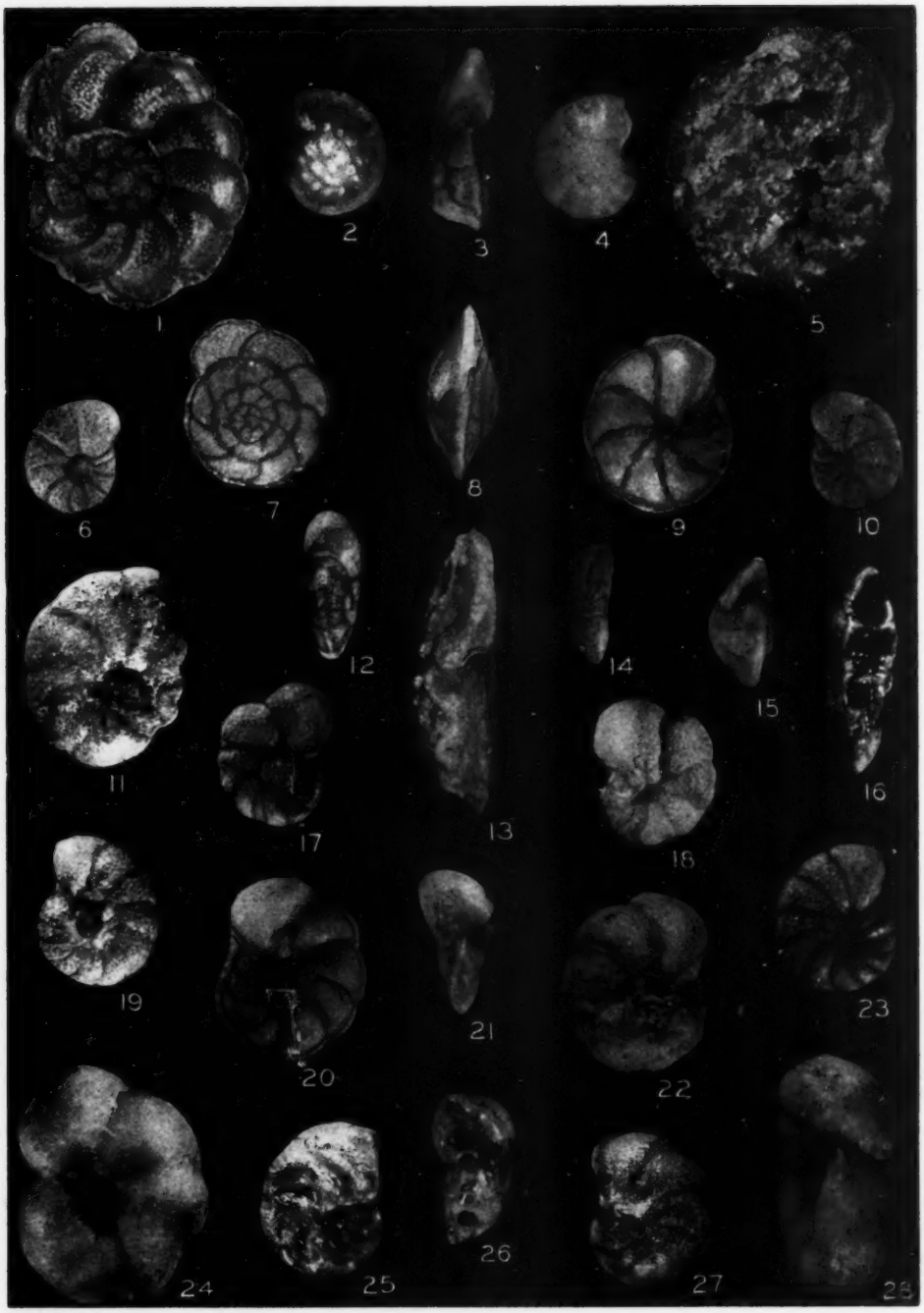
Figured specimen.—No. 7515, Stanford Univ. Paleo. Type Coll., from station 4.

EXPLANATION OF PLATE 108

FIGS. *1, 4—Eponides yeguaensis* Weinzierl and Applin. *1*, Dorsal view. *4*, Ventral view, ×40. (p. 608)
2, 3—Globigerina triloculinoides Plummer. *2*, Dorsal view. *3*, Ventral view, ×40. (p. 609)
5, 6—Pullenia? sp. a., ×40. (p. 609)
7, 13, 14—Cassidulina globosa Hantken. *7*, Side view. *13, 14*, Apertural views, ×75. (p. 609)
8, 12—Pullenia salisburyi R. E. and K. C. Stewart. *8*, Side view. *12*, Apertural view, ×50. (p. 609)
9, 11—Anomalina sp. a, ×65. (p. 610)
10—Ellipsonodosaria cf. *E. cocoaensis* (Cushman), ×40. (p. 608)
15, 18—Siphonina claibornensis Cushman subspecies *cowlitzensis* Beck, n. subsp. *15*, Apertural view. *18*, Ventral view. Holotype, ×40. (p. 608)
16, 17, 19—Eponides minimus Cushman. *16*, Dorsal view. *17*, Ventral view. *19*, Peripheral view. ×50. (p. 608)
20, 24—Ceratobulimina washburnei Cushman and Schenck. *20*, Dorsal view. *24*, Peripheral view, ×40. (p. 609)
21-23—Valvulineria cf. *V. scrobiculata* (Schwager). *21*, Dorsal view. *22*, Peripheral view. *23*, Ventral view, ×40. (p. 608)
25—Orbulina universa d'Orbigny, ×50. (p. 609)
26, 28—Angulogerina hannai Beck, n. sp. *26*. Apertural view. *28*, Side view. Holotype, ×50. (p. 607)
27, 29, 31—Eponides condoni Cushman and Schenck. *27*, Dorsal view. *29*, Peripheral view. *31*, Ventral view, ×100. (p. 608)
30—Uvigerina cf. *U. churchi* Cushman and Siegfus, ×40. (p. 607)



Beck, Eocene Foraminifera



Beck, Eocene Foraminifera

Remarks.—This small specimen can not be definitely identified generically because the aperture is obscured.

Genus PLANULINA d'Orbigny, 1826
PLANULINA? sp. A
Plate 109, figures 11, 16

Dimensions.—Length, 0.60+ mm.; breadth, 0.48+ mm.; thickness, 0.10 mm.

Figured specimen.—No. 7516, Stanford Univ. Paleo. Type. Coll., from station 1.

Remarks.—A few broken specimens probably referable to this genus were found in the highest beds at Cowlitz River.

Genus CIBICIDES Montfort, 1808
CIBICIDES BAILEYI Beck, n. sp.
Plate 109, figures 7–9

Test medium-sized, nearly biconvex, periphery acute, lobulate, slightly keeled; chambers 8 to 9 in last whorl, becoming slightly higher as added; sutures distinct, hyaline, flush with surface, curved backward; wall polished, perforate; aperture small, extending dorsally across periphery and slightly beyond to outer base of last chamber. Length, 0.55 mm.; breadth, 0.47 mm.; thickness, 0.21.

Holotype.—No. 7517, Stanford Univ. Paleo. Type Coll., from station 54.

Remarks.—This species resembles *Cibicides martinezensis* Cushman and Barksdale (1930) but differs in having a greater number of spiral sutures, higher chambers, and in being larger.

CIBICIDES HODGEI Cushman and Schenck
Plate 109, figures 24–28

Cibicides hodgei CUSHMAN and SCHENCK, 1928, California Univ., Dept. Geol. Sci. Bull., vol. 17, no. 9, p. 315, pl. 45, figs. 3, 5.

Dimensions.—Length, 0.45–0.75 mm.; breadth, 0.35–55 mm.; thickness, 0.25–0.33 mm.

Hypotype.—No. 7518, Stanford Univ. Paleo. Type Coll., from station 14.

Remarks.—Figures 24 and 28 show a large form that is possibly aberrant. Some topotypes from the Bassendorf formation of Coos Bay, Oregon, however, are similar and this species may be polymorphic. Figures 25–27 are typical, but show a slightly immature form. Comparison of topotypes with topotypes of *Anomalina crassisepta* Cushman and Siegfus (1935, p. 95, pl. 14, figs. 12 a, c) suggest that they are so closely similar that further studies may prove them to be conspecific.

CIBICIDES LOBATULUS (Walker and Jacob)
Plate 109, figures 17, 18, 21

Nautilus lobatula WALKER and JACOB, 1798, Adam's Essays on the Microscope, Kanmacher's Ed. p. 642, pl. 14, fig. 36. (Non vide.)

EXPLANATION OF PLATE 109

FIGS. *1, 5, 13—Cibicides natlandi* Beck, n. sp. *1*, Dorsal view. *5*, Ventral view. *13*, Peripheral view. Holotype, ×40. (p. 612)

2, 4, 15—Cibicides mcmastersi Beck, n. sp. *2*, Dorsal view. *4*, Ventral view. *15*, Peripheral view. Holotype, ×50. (p. 612)

3, 20, 22—Cibicides natlandi olequaensis Beck, n. subsp. *3*, Peripheral view. *20*, Dorsal view. *22*, Ventral view. Holotype, ×40. (p. 612)

6, 10, 14—Anomalina? sp. b. *6*, Dorsal view. *10*, Ventral view. *14*, Peripheral view, ×50. (p. 610)

7–9—Cibicides baileyi Beck, n. sp. *7*, Dorsal view. *8*, Peripheral view. *9*, Ventral view. Holotype, ×45. (p. 611)

11, 16—Planulina? sp. a., ×50. (p. 611)

12, 19, 23—Anomalina costiana Weinzierl and Applin. *12*, Peripheral view. *19*, Dorsal view. *23*, Ventral view, ×45. (p. 609)

17, 18, 21—Cibicides lobatulus (Walker and Jacob). *17*, Dorsal view. *18*, Ventral view. *21*, Peripheral view, ×50. (p. 611)

24–28—Cibicides hodgei Cushman and Schenck. Two different specimens. *24, 28*, Views of an unusually large form. *25*, Dorsal view. *26*, Peripheral view of *25*. *27*, Ventral view of *25*, ×50. (p. 611)

Dimensions.—Height, 0.40 mm.; breadth, 0.34 mm. thickness, 0.22 mm.

Hypotype.—No. 7519, Stanford Univ. Paleo. Type Coll., from station 27.

Remarks.—These rare specimens seem identical with the widespread, commonly figured *C. lobatulus* from the Tertiary.

CIBICIDES MCMASTERSI Beck, n. sp.
Plate 109, figures 2, 4, 15

Test small, planoconvex, periphery acute; chambers distinct in last coil, obscured in center by clear shell material both ventrally and dorsally, of uniform shape, becoming slightly wider as added; sutures slightly raised, hyaline, moderately limbate, bent backward; wall coarsely perforate between sutures; aperture extending from ventral side across periphery to base of last formed chamber on dorsal side. Diameter, 0.34 mm.; breadth, 0.30 mm.; thickness, 0.17 mm.

Holotype.—No. 7520, Stanford Univ. Paleo. Type Coll., from station 9.

Remarks.—This species resembles *C. sassei* Cole of Cushman and Dusenbury (1934, p. 64, pl. 9, figs. 5 a–c) but differs in having more chambers, a narrower apertural face, and less lobulation of the periphery. *Cibicides* sp. A of Cushman and McMasters (1936), is very similar and probably conspecific.

CIBICIDES NATLANDI Beck, n. sp.
Plate 109, figures 1, 5, 13

Test large, generally planoconvex, dorsal side either convex or concave, periphery acute, lobulate, generally sharply keeled; chambers distinct, 9 to 12 in last whorl, gradually increasing in size as added; sutures distinct dorsally, hyaline, limbate, early ones flush with surface, latter ones slightly depressed, curved backward, ventral sutures often obscured by extraneous shell material, when observable somewhat beaded, narrow, raised; wall polished, coarsely perforate: aperture at base of last-formed chamber on dorsal side, extending over periphery to ventral side. Length, 0.93 mm.; breadth, 0.80 mm.; thickness, 0.20 mm.

Holotype.—No. 7521, Stanford Univ. Paleo. Type Coll., from station 10.

Remarks.—This species is abundant in the Cowlitz beds. It was identified as *Truncatulina wuellerstorfi* (Schwager) by Hanna and Hanna (1924) but it is distinct from that species. It resembles *Planulina haydoni* Cushman and Schenck (1928), but differs in not being produced ventrally, and typically in having a keeled periphery. *P. haydoni* is probably a *Cibicides*, that evolved from *C. natlandi* which is completely involute ventrally, with an aperture that crosses the periphery to the dorsal side. This species is common in the upper type Tejon formation at the south end of San Joaquin Valley, California.

CIBICIDES NATLANDI OLEQUAENSIS Beck, n. subsp.
Plate 109, figures 3, 20, 22

Dimensions.—Length, 0.61 mm.; breadth, 0.49 mm.; thickness, 0.17 mm.

Holotype.—No. 7522, Stanford Univ. Paleo. Type Coll., from station 21.

Remarks.—This subspecies differs from the typical form in being smaller, having more incised sutures, a more inflated last chamber, and a polished ventral side.

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PERMIAN OSTRACODES

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ABSTRACT—Permian ostracodes of Kansas and Nebraska are fairly well known and include many excellent index species but the faunas of Texas and the Southwest have been little investigated. This paper is largely based on the study of material contributed by several collectors. Many new and distinctive species have been recognized but their formal description has not been attempted.

After abrief consideration of ostracode environments, specific variation and evolutionary trends, this paper discusses the outstanding features of various faunas and their stratigraphic and geographic variations. Described species of index value are listed and undescribed species are briefly characterized so that they can be recognized by others working with these faunas. Certain broad correlations are indicated.

This study has clearly shown that the Permian ostracodes include many excellent index species and their further investigation will certainly yield data of great value for stratigraphic correlation.

INTRODUCTION

OSTRACODES ARE abundant and varied not only in the Pennsylvanian but also in many parts of the Permian system of the United States. Numerous beds in the Wolfcamp series of both the northern mid-Continent region and Texas abound with ostracodes, and they are by no means rare in the higher Leonard series. Some also have been found in the Middle Permian Guadalupe series where they seemingly make their final appearance in the Permian of this country. Of the 200 or more known Permian species less than half have been named and described; doubtless many more species will be discovered, particularly in the relatively unknown microfaunas of the Leonard and the Guadalupe series. In the eastern United States a few ostracodes have been found in the Dunkard series (Jones, 1905, and Holland, 1934).

ACKNOWLEDGEMENTS

Most of the Permian ostracodes of Nebraska and Kansas have been described, but inasmuch as only a few Texas species were known, it has been necessary to make a preliminary survey of the Texas ostracodes in order to compare them with the northern faunas.

I wish to express my thanks to the paleontologists who generously supplied the material which made this study possible. Mr. M. E. Upson kindly loaned numerous slides of ostracodes representing the faunas of most of the important horizons in north-central Texas from the Camp Colorado to the Lueders formation usually from several localities. Material furnished by Mrs. Helen Jeanne Plummer yielded a large ostracode fauna from the Horse Creek formation. Dr. J. Brookes Knight and Mr. Stanaslav Kriz sent material from the Hueco and Bone Spring formations, the latter with many new species. Mr. Robert Roth contributed material from the Saddle Creek formation and also Leonard samples rich in ostracodes. Deep well samples containing many ostracodes from Leonard strata were furnished by Dr. H. H. Bradfield. Mr. Chalmer L. Cooper loaned specimens from the fresh-water Dunkard series of the eastern states. Finally I must thank Dr. Norman Newell and Mr. Irving Hamilton for paratypes of their recently described lower Word fauna (Hamilton, 1942), and Mr. Ronald K. De Ford for translations of articles on Russian Permian ostracodes.

ENVIRONMENTS

Living ostracodes are both benthonic and free swimming. They occur in both fresh and salt water and can exist in such unfavorable places as sewers, pools in dark caves, hot springs and sulphur water. This hardiness accounts in part for the adaptability of some fossil species which may occur not only in calcareous shale but also in grey, greenish, or black shale, sandy shale, limestone, sandy limestone, or sand. The

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occurrence of certain species in many types of rocks is an indication, however, not only of adaptability but also of the ease with which the tiny, lightweight shells may be widely distributed by waves or currents.

Almost all Permian ostracodes have been considered marine except for a few species, mostly referred to *Carbonita*, which occur in the fresh-water Dunkard series of Maryland, Pennsylvania, Ohio and West Virginia. One of these Dunkard species, or a very closely related form, is not uncommon in the lower Permian of Kansas and Nebraska as high as the Wreford formation, occurring with *Bairdia beedei*, *Amphissites pinguis* and other typically marine fossils. Jones and Kirby in 1879 record that *Carbonita*

> occur in bituminous shales, in blackband and clayband ironstones, in parrot-coals, and in impure limestones. . . . Whenever conditions suitable for the laying down of *coal-measures* prevailed, there these Entomostraca flourished.

But in some instances they were found

> associated with fossils that are either estuarine or marine, or have decided marine affinities.

Besides *Carbonita* the grey and black shales of Pennsylvanian and Permian age often carry *Cavellina*, *Geisina*, *Healdia* and *Seminolites* which are also common in other types of sediments. Ostracodes other than those in the dark shales probably have facies relationships which may be revealed by correlations of lithology and the complete faunas of narrow zones.

SPECIFIC VARIATIONS

Like living ostracodes and other crustaceans, the fossil species shed their hard, horny or calcareous shells and develop new ones several times during growth. The large percentage of immature molts in Paleozoic ostracode collections, as compared to the smaller proportion in Cretaceous and later faunas, suggests that Paleozoic ostracodes molted more frequently than those of later times. Permian representatives of the Kirkbyidae and Kloedenellidae evidently molted especially often, some individuals, perhaps as many as six times.

Molts of immature ostracodes may be recognized not only by their small size but by other characters which serve to differentiate them from mature specimens, such as thinness of shell, undevelopment of inner calcareous lamellae, lack of fullness of carapace particularly in the posterior portion, tapering of posterior outline in side view, narrowness of overlap, and only partial development of ornamentation and hinge structures. Neanic molts which differ greatly from geronic may suggest relationships to ancestral forms not otherwise apparent. Study of such early molts is as necessary to an understanding of ostracode classification and phylogeny as a knowledge of the early chambers of the Foraminifera and ammonoids is to their classification.

Another type of variation is due to difference in sex and is not only of systemic significance but its recognition is the key to ostracode orientation. In the Permian, sexual dimorphism is not always obvious in the Bairdiidae and Kirbyidae, but mature males and females of the Kloedenellidae, Hollinellidae and Cytherellidae are easily distinguished.

The proper discrimination between specific and individual variation may be difficult but considerable latitude in the length-height ratio probably should be allowed within most species.

Failure to recognize differences as being due to age, sex or individual variation leads to confusion and over-naming; but once specific variability is understood and the characteristic variations are known, each species can be used with confidence in stratigraphic work.

EVOLUTIONARY TRENDS

Diminution in size.—The oldest known ostracodes of Canadian and early Ordovician times are mostly simple, very large species, many of which attained a length of several to 30 millimeters. Younger ostracodes are smaller and in general show a gradual diminution in size throughout the Paleozoic era. Pennsylvanian species, which seldom much exceed 1 millimeter in length, are quite small as compared to Ordovician species, and Permian species, particularly in the northern mid-continental region, are on the whole even smaller than Pennsylvanian forms. For example the large flat cavellinas of the John's Valley shale reach a length of 1.27 mm., the typical upper Pennsylvanian *Cavellina nebrascensis*, 1.17 mm., but the largest species of Leonard cavellinas seldom

if ever exceed 1 mm. Almost all Mississippian and early Pennsylvanian members of the genus *Amphissites* attain a length of 1 to 1.5 mm., but Permian species are less than 1 mm. in length. Mississippian species of *Healdia* attain a length of from 0.75 to 1.50 mm., lower Pennsylvanian species range from 0.40 to 0.75 mm., but the largest Permian species seldom exceed 0.50 mm. Younger species of other genera, such as *Kirkbya*, *Hollinella*, *Monoceratina* and *Bythocypris*, similarly are smaller.

Complexity of articulation.—Numerous Carboniferous ostracodes have grooved hinges, many with single terminal teeth and sockets much more complex than the very simple hinge structures of Ordovician species. Still more complex articulation, consisting of crenulated hinges and multiple teeth and sockets, developed in the Cretaceous. Evolution of the simple grooved hinge of the Carboniferous into the crenulated hinge of the Cretaceous is well illustrated in the genus *Monoceratina*.

Diverse trends.—Such widely differing families and genera occur among Carboniferous ostracodes that other evolutionary trends are not apparent in the group as a whole. In the Permian system alone this diversity is illustrated by the more than 35 genera referred to many families. Species of some genera tend to lose ornamentation but those of other genera acquire it. *Healdia* shows a loss in ornamentation. The typical basal Pennsylvanian *Healdia* is characterized by a distinct, short, vertical ridge connecting two long spines posteriorly. By mid-Pennsylvanian time these spines were much shortened and the ridge less sharp, as in the type species, *H. simplex*. The common *H. winfieldensis* of the Permian retains only remnants of spines, most prominent in young specimens, and no ridges. By Leonard time the descendents of *H. winfieldensis* had lost almost all trace of even these vestigial spines. In contrast, *Monoceratina* began in the Devonian as a simple primitian form with an inconspicuous ventral spine which by Pennsylvanian time had developed on some species into a horn-like process. By Jurassic time the greatly expanded genus had acquired reticulation and other ornamentation in addition to hinge teeth.

During the lower Permian *Knoxina bolliaformis* evolved comparatively rapidly into *Knoxina lecta* with the development of several horizontal ridges. *Knoxina* belongs to the straight-hinged, sulcate Kloedenellidae, and is characterized by two protuberances on the postventral portions of the valves of young and of male specimens. The genus occurs in the Chester series of Illinois but, peculiarly, it has not been recognized in the Pennsylvanian except for *Knoxina bolliaformis* (better known formerly as *Jonesina bolliaformis*) at the top of that system. This species is abundant and widespread in the lower Permian strata of Nebraska, Kansas, and Texas. In the Elm Creek formation of the Belle Plains group of Texas specimens first appear which show incipient ridges, and in the Bead Mountain formation these have developed into a species with distinct anterodorsal and ventral marginal ridges. In the higher Arroya formation, Clear Fork group, of Tom Green County, Texas, *Knoxina lecta* represents a further development of this form, another horizontal ridge having been added between the sulcus and the marginal ridge. This evolution seems to disprove the postulation that the Arroya assemblage is "an indigenous and secluded fauna" (Coryell and Rogatz, 1932).

Opposite trends may develop even within one family as in the Kirkbyidae. During the Mississippian period many large and beautifully ornamented species of *Amphissites* flourished. Later these gave place to a few small, hardy, very long ranging and mostly simple species which are almost the only *Amphissites* found in the Permian. Conversely, the genera *Kirkbya* and *Knightina* developed many highly ornamented species only in the Permian, when both genera reached culmination.

The diversity of the ostracodes is further shown by the various modifications characteristic of different genera. The repression of certain structures coincident with the accentuation of others may be observed in a comparison of basal Pennsylvanian species with later species of *Hollinella*. This genus is composed of straight-hinged, sulcate species with a node on each side of the sulcus and a frill around the free edges. Early species possess wide frills and broad low

nodes but later Pennsylvanian and Permian species have narrower frills and nodes that are typically high with the large anterior node bulbous, pointed or flattened at the top.

APPEARANCE OF PERMIAN GENERA

The oldest Permian genera, *Bythocypris* and *Pontocypris*, are known from the Ordovician, and the small beginnings of several other Permian genera such as *Paraparchites*, *Hollinella*, *Cavellina*, *Kirkbya*, *Amphissites*, *Monoceratina*, *Microcheilinella*, *Healdia* and *Bairdia* occur in the Devonian. By Mississippian time these and other newly appearing genera such as *Glyptopleura*, *Cornigella*, *Acratia*, *Knightina*, *Sansabella*, *Knoxina*, *Carbonita* and *Silenites* had become conspicuous and because most of the early Paleozoic genera had disappeared the aspect of the Paleozoic faunas was much changed (see Cooper, 1942, pp. 770–773 and chart). By the end of the Mississippian at least one-half of the Permian genera were in existence. During the Pennsylvanian period, or possibly earlier, *Geisina*, *Ellipsella*, *Kellettina*, *Bairdianella*, and *Basslerella* appeared.

PENNSYLVANIAN AND PERMIAN FAUNAS

Comparison of Pennsylvanian and Permian ostracode faunas shows differences of species rather than of genera because most Pennsylvanian genera continue into the Permian. Some, however, do not. Two of the more common upper Mississippian and basal Pennsylvanian genera which disappeared in lower Pennsylvanian time are the noded genus *Glyptopleurina* and *Graphiadactyllis*, which is covered with delicate inosculating ridges. Other genera which disappeared a little later include *Ardmorea* which is not found above the Missouri series; and *Waylandella*, *Seminolites*, *Sulcella*, and *Moorites* which did not survive the Pennsylvanian. In the lower Permian of the mid-Continent region *Haworthina* is the only genus not known also in Pennsylvanian strata.

PENNSYLVANIAN AND PERMIAN SPECIES

Although ostracode genera of the Pennsylvanian and Permian systems differ little many species are quite distinct. Some Pennsylvanian species were very short-lived. The three-noded *Hollinella radlerae* characterizes a narrow zone in the middle Pennsylvanian Chanute shale of Kansas and Nebraska. The widespread *Amphissites dattonensis* is found no higher than the upper Pennsylvanian Howard formation. *Hollinella burlingamensis*, another easily recognizable hollinellid, is known only in or near the Burlingame formation of upper Pennsylvanian age in both Kansas and Oklahoma where it is commonly associated with the foraminifers *Bradyina* and *Tuberatina*, the latter seemingly making its final appearance in Kansas.

About 75 per cent of the species found in the Wolfcamp series of the mid-Continent area are known only from the Permian. In the higher Leonard series 95 per cent are known only from the Permian, and all Pennsylvanian species seem to have disappeared from the Guadalupe series.

The fact that relatively few Permian species were very long-lived is somewhat obscured by the abundant molts of *Amphissites pinguis*, *A. centronota*, *Roundyella simplicissimus* and *Bairdia beedei*, all common long ranging forms. *R. simplicissimus* and *A. pinguis* persisted from Des Moines into Leonard time without perceptible change, and *Macrocypris occidentalis*, known also as *M. garrisonensis*, ranges from middle Pennsylvanian rocks to the Permian Yeso formation. Such common, hardy species as these became the first and most extensively known ostracodes, and for this reason the value of ostracodes as guide fossils has been questioned. Now that their long ranges have been recognized such species are disregarded in detailed stratigraphic correlation and the many significantly restricted ostracodes are used.

During the Permian, however, several long ranging species finally gave rise to modified forms of stratigraphic value. *Amphissites centronota* known throughout Pennsylvanian and Permian strata developed in the *Schwagerina crassitectoria* zone of the Leonard series into a species with another short, diagonal ridge. The ever-present *Bairdia beedei* found first above the lower Pennsylvanian Boggy formation of Okla-

homa becomes useful when in the Permian Elm Creek formation a centrally located circular prominence is developed on the smaller valve of a few mature specimens. This prominence, related to the large adductor muscle, foreshadows a boss which becomes more prominent until in the Lueders formation of Leonard age it is well developed on both valves. This form is very prolific during much if not all of the Leonard and it is one of the best Leonard markers.

LOWER PERMIAN—WOLFCAMP

Kansas and Nebraska.—Permian ostracodes are probably even more diagnostic than Pennsylvanian. Very fossiliferous strata occur in the Permian of Kansas and Nebraska up to and including the Herington limestone. Ostracodes are an important element of most faunas with the exception of that in the dolomitic Herington limestone where only a few ubiquitous, hardy, and long-ranging species of little stratigraphic significance accompany the conodonts, otoliths and large pelecypods. The limy, fossiliferous, lower Permian sediments of Kansas become redder and more dolomitic as they dip westward, and the ostracodes become increasingly scarce and finally disappear in the redbeds of westernmost Kansas and Colorado.

Most of the ostracode species of the northern Permian and their stratigraphic ranges are now fairly well known through the work of Ulrich and Bassler, Upson, Harris and Lalicker, and Kellett. Only a few scattered species, however, have been reported from Texas although ostracodes occur abundantly in the Texas Wolfcamp. Consequently in this survey it is necessary to use the northern ostracodes as a standard for comparison.

Index species.—The Lower Permian beds of Kansas and Nebraska, carry many diagnostic ostracodes, 38 of the 62 species being known only in the Permian. The basal Permian is marked by 15 species which appear below the Grenola formation, many of which also occur above the Grenola.

Some of the most abundant, easily recognized and short-lived Kansas-Nebraska species belong to the Hollinellidae and Kirkbyidae. *Hollinella nevensis*, recognized by the broadly confluent anterior node and ventral ridge, is limited to the Grenola formation, except for a nontypical form in the Funston limestone. A related species, *Hollinella emaciata*, in which the ventral ridge presents a pinched emaciated appearance, occurs from the Cottonwood formation to the Fort Riley limestone in Kansas and Nebraska and also near the base of the Belle Plains group in Texas. The very thick *Kirkbya wymani* is rare in the basal Permian below the Cottonwood formation, but common from the Cottonwood to the top of the Chase group; in Texas it is most abundant in the Coleman Junction formation. The rarer *Kirkbya moorei* is easily recognized by the cone-shaped central elevation and is as yet known only from the Grenola formation in Oklahoma, the Wreford formation of Kansas, and the Coleman Junction formation of Texas. *Knightina texana* is characteristic of all of the Kansas Permian to the top of the Chase group. *K. texana* has been reported in the Pennsylvanian of Menard County, Texas, but after examining the original material I believe that the young of another species was mistakenly identified. The beautifully sculptured *Knightina bassleri* is locally abundant in Kansas and Nebraska from the Grenola formation to the Fort Riley limestone; in Texas it occurs in the Coleman Junction and Hordes Creek formations, but not as abundantly as in Kansas. The two small but easily identified species *Knightina minuta* and *K. incurva* occur together in the upper fossiliferous Permian of Kansas, and in Texas they are characteristic of the Belle Plains group, particularly of the lower part.

The accompanying chart gives the vertical distribution of 64 species of ostracodes recognized in the Permian of Kansas and Nebraska and their stratigraphic ranges as now known in north-central Texas. Occurring with these species in Texas are more than 20 unnamed species which have not yet been found in the north. They are omitted from the chart, although some are briefly discussed later. The lowest line of the Kansas chart shows which species also occur in Pennsylvanian strata.

Oklahoma.—Ostracodes are found no higher than the Wreford formation in northern Oklahoma and to the south they disappear in the red and sandy Permian which covers much of that state.

Permian ostracodes again appear at the Cement oil field of southern Oklahoma in an arenaceous limestone zone 30 feet thick, approximately 400 feet above the base of the Permian. This zone is characterized by *Paraparchites punctatus* and *Bythocypris erectus*, species possibly younger than Wolfcamp.

Texas species east of Midland basin.—In

PERMIAN OSTRACODES OF KANSAS AND TEXAS

	Texas											Kansas									
	Wolfcamp												Council Grove Group						Chase Group		
× = Common 0 = Rare * Small.	Saddle Creek	Camp Colorado	Shale above Dothan	Horse Creek	Sedwick	Santa Anna Branch	Coleman Junction	Hordes Creek	Fisk	Elm Creek	Bead Mountain	Pennsylvanian	Admire	Americus	Foraker—Red Eagle	Grenola	Cottonwood	Garrison	Wreford	Fort Riley	Doyle	Winfield
Acratia typica		0														0						
Amphissites centronota	×	×		0		0						×	×	0	×	×	×		×			0
Amphissites pinguis	×	×		0		0	×	0	0	0		×	×	0	×	×	×	0	×		×	0
Bairdia forakerensis															0							
Bairdia beedei	×		0	0	0	0		×		×	?	×	×		×	×	×	×	×	×	×	×
Bairdia deloi				×											×				0			
Bairdia eissensis																		0				
Bairdia florenaensis		0		0		0	0	0	×	×			×	×	×	×	×	×	×			
Bairdia garrisonensis												×	0		×		0		0			
Bairdia geisi																0	0					
Bairdia glennensis												×			×							
Bairdia hoffmanae		0										×		0								
Bairdia hoxbarensis		0										×			×	0	0		0			
Bairdia nevensis				0												0						
Bairdia maxeyi							0	×	0	×	0							×	×			
Bairdia pompilioides	0	×										×		0	×				×			
Bairdia radlerae							0									0			0			
Bairdia reussiana		?		×		0	0					0		0	×	0	×	0	×	×		×
Bairdia seminalis	0	0		×								×	×	×	×	×	×		?			
Bairdia verwiebei					0			×								0	0	×	×			0
Basslerella crassa															×							
Basslerella firma				0									0	0	×				0			0
Basslerella rothi		0		0			0			0					×							
Bythocypris pediformis	×			×			×			×		×		0	×	×	×		×	×		
Carbonita tumida			×		×			×							0			×				
Carbonita magna		0										×				0		0				
Cavellina edmistoni				0		×		×	0	0		0		0		×	×	×	×			
Cavellina nebrascensis				?*	*							×	×	×	×	×		×				
Cavellina chasensis																			0			
Cornigella binoda																0			0			
Cornigella parva																				0		0
Cyathus ulrichi												×			0							
Ellipsella distenta									0			×			×	0			0			0
Geisina papillosa															0							
Geisina primitioides														0	×	×						
Geisina upsoni																		0				
Glyptopleura triserta									0										×			
Haworthina bulleta																×			0			
Healdia parallela														0	0							
Healdia winfieldensis			×			×	0	×	×				0	0	×	×	0		0			×
Hollinella crassamarginata						×							0	0	×	0	×		×		?	?
Hollinella emaciata									×								×	×	×	×		?
Hollinella nevensis															0	×		0				
Hollinella ulrichi		×		×		0	×		×	×		?	×	×	×	×	×	×	×	×	×	×
Kellettina robusta	×	×		×	0	0								0	×				×			
Kirkbya canyonensis				0											×	?						
Kirkbya moorei							×												×			
Kirkbya valida															×							
Kirkbya wymani					0	0	×									0	×		×			
Knightina bassleri			0				×	×	×							×		×	×	×		×
Knightina incurva									×	0	×								0		×	×
Knightina minuta									×			0						0	0	×		0
Knightina texana	0	×			×	×	×	0	×	0						0	×		×	×		×
Knoxina bolliaformis			×		×	×		×	×	×		0	×	×	×	×	×	×	×	×		×
Macrocypris occidentalis		×					0					×				0	0		0			
Microchilinella inflata		0		×								0	0			0						
Monoceratina lewisi			0									×	×		×	×	×		×	×		0
Paraparchites gibbosus																		×				
Paraparchites humerosus			0					0					×		×			×	×	×		
Pseudoparaparchites kansensis												0			0		0					
Roundyella simplicissimus		×		×	×	×	×	×	×			×			×				×			×
Silenites lenticularis	×		×	×								×		×	×				0			

Texas, ostracodes are common in the Wolfcamp series where their assemblages resemble those of like age in Kansas. Of the northern species, over two-thirds or 43, have been found in Texas. These include most of the common Kansas species and most of those not as yet recorded in Texas are rare in Kansas.

Studies of Texas ostracodes have been based on only a moderate amount of material and, therefore, are not exhaustive, and the following conclusions, particularly those concerning western Texas, are tentative. The known ranges of some species may be extended, and the ranges of others may be restricted by more discriminating study.

Twenty or more unnamed species occurring in north-central Texas are unknown in Kansas or Nebraska. Many of them seem to be limited in stratigraphic range.

Texas index species.—At least six species of *Cavellina*, of very limited vertical range occur in the Wolfcamp series of Texas and several others are present in younger beds. All are more or less abundant. In contrast, only a few species of this genus occur in Kansas: the common later Pennsylvanian *C. nebrascensis*, found as high as the Grenola formation; *C. edmistoni;* and the rare *C. chaesensis. C. edmistoni* is also found in the basal Permian of Texas but it is replaced in the shale above the Dothan formation by another small, somewhat similar, but higher species. This in turn gives way in the Santa Anna Branch formation, 12 to 27 feet below the Coleman Junction limestone in Callahan County, to a species which is larger, higher, and dorsally more angular, with females which are posteriorly very thick. In a still higher zone of the formation also below the Coleman Junction limestone another form is recognizable in which truncation of the postventral angle results in a carapace roughly diamond-shaped in lateral view. A related but distinctly more elongate species is present in the Hordes Creek formation 3 miles east of Coleman.

The larger, broader, flatter, and more nearly rectangular cavellinas of the Coleman Junction formation evidently were derived from different stock. The flat male of the Coleman Junction species is easily identified by the broadly curved dorsum and narrow apparent overlap. In the Fisk formation is a short, thick *Cavellina* with a broadly curved dorsum and wide apparent overlap. A related species in the Grape Creek formation is not quite so short and high. The Lueders formation has yielded an easily recognizable, small, very short *Cavellina*, posteriorly blunt in lateral view. Another species has been described by Coryell and Rogatz from the Arroya formation.

Among species of other genera which may prove useful is the *Bairdia* with a spine which occurs in the early Permian Camp Colorado formation. Another *Bairdia* is the southern relative of the large *B. garrisonensis* of Kansas and Nebraska which differs only in having a distinct indentation on the dorsal part of the smaller valve. *B. garrisonensis* persists from the Foraker to the Wreford formation; its southern relative has been found just above the Dothan limestone, quite abundantly in the Horse Creek formation, and in the Coleman Junction formation. Abundant specimens of a high, short *Geisina* characterize the Sedwick formation, and a *Hollinella* with high pointed nodes is present in the Santa Anna Branch formation.

The Coleman Junction formation carries a distinctive ostracode assemblage which includes the *Cavellina* described above, a *Kirkbya* with two horizontal parallel ridges, and *Kirkbyina inflata*. Two species of *Paraparchites* likewise occur. One, tiny, plump, and dorsally thickened, is also rarely present below in the Horse Creek formation. This is the only *Paraparchites* known below the Coleman Junction formation. The other species possesses a short spine on one valve only, and occurs in the upper part of the Coleman Junction formation. The absence of *Paraparchites humerosus* in the lower Permian of Texas is remarkable as this species is so abundant in the basal Permian of Kansas as to be commonly found in well samples. According to Mr. W. C. Fritz (personal communication), *Paraparchites* is abundant in Texas in both well and outcrop material only above the Coleman Junction formation.

The Elm Creek formation is notable for an abundance of somewhat elongate, dorsally thickened *Bairdia*, shorter and dorsally more arched than *B. reussiana*. This and other similar species are common in the

Leonard series. A *Knoxina* with incipient ridges which is a forerunner of the Arroya *Knoxina lecta* is conspicuous in the Elm Creek.

North-central Texas.—Various boundaries between the Wolfcamp and Leonard series in north-central Texas have been suggested. Recently Cheney selected the base of the Belle Plains group because of an important disconformity. The basal Belle Plains ostracode faunas are, however, little different from those of the underlying formations and greater changes occur within the upper part of this group where the Elm Creek and the Bead Mountain faunas are quite different, the latter being decidedly Leonard in aspect. The changes between Wolfcamp and Leonard ostracode faunas are, however, gradual rather than abrupt, for the Elm Creek carries certain typically Leonard forms of *Bairdia*, and in the Elm Creek *Bairdia beedei* and *Knoxina bolliaformis* show faint beginnings of the nodes and ridges characteristic of their Leonard descendants.

Elias and Romer suggest that the Wolfcamp-Leonard boundary may be as high as the top of the Belle Plains group, but the ostracodes of the uppermost formation, the Bead Mountain, are very similar to those of the overlying Clyde group. Ostracodes indicate, therefore, that the Wolfcamp-Leonard boundary is within the Belle Plains group as now defined, at the base or possibly at the top of the Valera formation. If other evidence substantiates this conclusion and the correlation suggested in the last section, the upper limit of the Wolfcamp series conveniently coincides with that of the Chase group.

West Texas.—Few ostracodes have been collected in west Texas but a fauna from the lower Hueco formation is of interest because of its surprising similarity to northern faunas. This fauna was obtained by Knight and Kriz, Localities 24A and 24B, Kriz, near the Hudspeth-Culbertson County line, probably in Culbertson County. Of its 25 species, all but one occur in north-central Texas, and all but three in Kansas. Many of these species range upward from the base of the Permian both in north-central Texas and Kansas but the presence of several diagnostic species indicates that the fauna is very near Coleman Junction in age. The most significant species are *Bairdia maxeyi* (which I once erroneously confused with *B. reussiana*), an unnamed *Bairdia* which is low and dorsally thickened, and a broad, flat *Cavellina*, all of which first appear in the Coleman Junction formation, along with the tiny, plump and dorsally thickened *Paraparchites* characteristic of that formation.

This widespread Wolfcamp fauna contrasts strongly with the conspicuously different faunas occurring in the Bone Spring formation, the Leonard of the Glass Mountains, and the Leonard in central Texas.

Europe.—The still wider distribution of many Lower Permian ostracodes is evidenced by the similarity of American species to those in the northern Urals and in the Ishimbaievo oil field of the U.S.S.R. Wolfcamp species occur in reef rocks of Sakmarian and Artinskian age and a few species resembling Leonard forms likewise are recorded. Of the thirty-four species from the Sakmarian *Pseudoschwagerina* zone of the northern Urals described by Glebowskaja (1938) eight are present in the lower Permian of Kansas.

Other Lower Permian ostracodes are known from Bohemia, the Saarbrucken coal field, India and New South Wales. Younger Permian species occur in England, Germany, Sicily and the U.S.S.R.

Correlations.—The many ostracodes of limited stratigraphic range common to the Nebraska-Kansas and the Texas areas are important for the correlation of Lower Permian strata. Their occurrences are shown on the accompanying chart and several of the more important species were discussed.

The Lower Permian ostracode faunas of successive Texas formations from the Saddle Creek to the Horse Creek are essentially the same, and with their *Silenites* and many small representatives of *Basslerella*, *Carbonita* and *Microchilinella*, they are quite similar to the basal Permian faunas of the northern region below the Grenola formation. The associated small foraminifera, especially the abundance of *Climaccammina* in both regions, also support this correlation. *Bradyina* is last seen in these strata in both Kansas and in the Pueblo of Texas where its occurrence has been reported by Helen Jeanne Plummer (personal communication).

The fauna of the Coleman Junction for-

mation with many specimens of *Kirkbya wymani* and *Hollinella ulrichi* differs little from that of the Kansas Cottonwood formation in which these species are dominant. *Climaccammina* has not been observed in north-central Texas above the Santa Anna Branch formation nor in Kansas above the top of the Cottonwood formation. A large, coarse, conical species of *Tetrataxis* first makes its appearance in the Cottonwood and the Coleman Junction formations.

Several ostracodes either make their first appearance or first become prominent just above the Cottonwood-Coleman Junction strata in both regions. Among these is *Bairdia verwiebei* which becomes conspicuous in the Wreford and Fisk formations, and *Glyptopleura triserta* found only in these formations. *Hollinella emaciata*, although present in the Cottonwood limestone, is abundant only in the Wreford and Fort Riley limestones of Kansas and in the Elm Creek formation of Texas. *Knightina incurva* and *K. minuta* occurring together in the Wreford and higher formations of Kansas likewise are characteristic of the Belle Plains group.

Tetrataxis dominates the microfaunas almost everywhere in the Wreford of Kansas and a very large dome-shaped species unknown in Texas is especially prominent. I have not observed *Tetrataxis* above the basal part of the Hordes Creek formation east of the Midland basin and conditions unfavorable to this genus probably developed in Texas before the domed species could migrate southward. In Kansas *Tetrataxis* is rare or absent above the Wreford and only 8 specimens were found in 11 upper Chase samples teeming with other foraminifera and ostracodes. Although it is absent or inconspicuous in the upper Wolfcamp series of both Kansas and Texas and is not known from Leonard strata of the Glass Mountains it occurs occasionally in the Bone Spring formation of far western Texas. It has also been found in upper Guadalupe material collected by Fountain and identified by Henbest.

At least the approximate correlation of the Barneston formation, which includes the very thick Fort Riley limestone and the Florence flint members, with the Elm Creek formation of Texas is indicated by faunal evidence. This is consistent with lithologic evidence as these formations include the lowest beds which are commonly dolomitic. If the Barneston and the Elm Creek formation are of the same age, the top of the Chase group probably coincides with either the base or the top of the Valera shale and anhydrite formation. The Bead Mountain formation at the top of the Belle Plains group is probably younger than the Chase group of Kansas inasmuch as the ostracode fauna includes only a few Kansas species, whereas the Elm Creek fauna possesses at least a dozen Chase species.

LOWER PERMIAN—LEONARD

Leonard ostracodes have been obtained from outcrops in north-central and west Texas and also from deep wells. These faunas consist mostly of distinctive species not found in the Wolfcamp series. A few long-ranging Pennsylvanian or Lower Permian species persist well up into the Leonard series, however, including *Roundyella simplicissimus*, *Amphissites pinguis*, *Knightina texana*, *K. minuta*, *Macrocypris occidentalis*, *Acratia typica*, *Basslerella rothi*, and a large form close to *Bairdia florenaensis*, the latter continuing into the basal part of the Word formation. These species are not as abundant in Leonard strata as they are in the Wolfcamp and they rarely make up a large percentage of any fauna.

Index species.—The best markers for the Leonard series as a whole are the humped *Bairdia* discussed previously, and a large, almost cylindrical *Bythocypris*-like species probably referable to *Darwinula*, a genus widespread in the Jurassic. The latter species has been observed as low as the Grape Creek formation in the Humble Nail Well No. 1, Shackelford County, at a depth of 110–115 feet, and both species are common throughout the Leonard series in other well samples and in the *Schwagerina crassitectoria* zone at several places near Marathon. They are not known from the Word series.

East of Midland basin.—The lowest beds east of the Midland Basin carrying typical Leonard ostracode assemblages occur, as noted before, in the Bead Mountain and overlying Grape Creek formations. Both carry a distinctive, tiny *Monoceratina* of primitive appearance, unknown elsewhere.

The Grape Creek carries, besides the ever present Leonard *Bairdia* and *Darwinula*? just discussed, a species of *Knoxina* differing from *K. lecta* of the Arroya formation in the lack of the horizontal ridge below the sulcus, a *Healdia* probably evolved from the common Wolfcamp species by the loss of almost all trace of spines, and two species of *Hollinella*—one with high, nonsymmetrical nodes, the other related to *H. emaciata* of the Wolfcamp.

The most distinctive elements of the Lueders fauna are the very short blunt *Cavellina* described above and a *Knightina* easily recognized by three nodes, two located dorsally and one at the center of the valve.

The youngest ostracode-bearing beds east of the Midland Basin are in the Clear Fork group. Coryell and Rogatz (1932) described species of *Paraparchites*, *Knoxina*, *Cavellina* and *Ellipsella* from outcrops, and they reported that this formation "is so replete with ostracode individuals that the including rock can really be termed an ostracode ooze."

Glass Mountains.—Little is known of the abundant ostracodes of the Leonard series of west Texas. Outcrop samples collected by Roth west of Gaptank (Roth, Loc. 260, zones B-D) about 400 feet above the base yielded well preserved specimens of about 40 species from the zone of *Schwagerina crassitectoria*. The fusulinids from Roth's collections have been described by Dunbar and Skinner.

One bed yielded 32 species, only 7 of which are known from earlier Permian strata. Nine others resemble earlier species species from which they were probably derived. Also present is a multicamerate, porcellaneous foraminifera, identified by Cushman and by Plummer as one of the earliest miliolids (personal communications).

In this fauna the Kirkbyidae is represented by about a dozen species referable to several genera, some of which are more ornamented than earlier species. Among them is a distinctive, very elongate *Kirkbya* with an unusual carinated shoulder. Extremely fine pits, much smaller than any on Lower Permian specimens, cover other species of *Kirkbya*, *Amphissites* and *Knightina*. *Amphissites centronota*, which continued almost unchanged from the Mississippian to the Permian, developed into a form with a short diagonal bar, and two species close to *Knightina incurva* and *K. minuta* of upper Chase age have more highly developed nodes and ridges.

Several of the many species of *Bairdia* are probably restricted stratigraphically. One of these, according to Bradfield, is found at a depth of 2300–2400 feet in the Sun Scott well No. 1, Terrell County, about 750 feet above the base of the Leonard. It is distinctive in that both ends are highly placed near and at an equal distance from the dorsum. This may be *B. dorsalis* of the German lower Zechstein.

A species of *Glyptopleura* has short vertical ridges connecting the characteristic horizontal ridges thus producing a network such as ornaments many Cretaceous ostracodes.

Knoxina in the *Schwagerina crassitectoria* zone lacks the ridges of *K. lecta* of the Arroya formation and is notable for the greater development of the dorsal spine together with the suppression of the ventral spine. It resembles some species of *Metacypris*, of Morrison and later age, and may indicate that part of that genus evolved from this subdivision of the Kloedenellidae.

Paraparchites.—Paraparchites is possibly the dominant Leonard genus. Specimens are abundant in samples from outcrops and deep wells, and the species are varied and diagnostic. Three species occur together in the *Schwagerina crassitectoria* zone:—one is almost circular and has an umbonate left valve with a flattened hinge area or dorsum; another has dorsal and ventral ridges on opposite valves; the third is rounded in lateral view but differs from the first in having a slightly depressed hinge. The first species occurs twice between the depths of 1460 and 1660 feet in the Sun Scott well No. 1, Terrell County, Texas, and between 1867 and 1873 feet in the Champlain Corder well No. 1 of the same county, about 1000 feet above the base of the Leonard as identified by Bradfield.

Another *Paraparchites* covered with mingled fine and coarse pore canals accompanies the almost circular species with flattened dorsum in the Sun Scott well. Still another species with the overlapping left valve both

umbonate and ventrally thickened occurs at a depth of 2300 to 2400 feet in this same well, 600 to 700 feet above Bradfield's base of the Leonard. The easily recognized *Paraparchites ornatus* described by Delo (1930) possibly is not found below the Leonard, but it seems to occur in deep wells at various horizons from the base of the Leonard up into the Word formation.

Specimens of *Paraparchites* become particularly abundant in the Clyde group of the Leonard in north-central Texas and continue to be prominent in younger Leonard faunas both in outcrops and wells. Specimens obtained by Bradfield from middle Clyde strata in the Humble Nail No. 1 well, Shackelford County, at a depth of 100–105 feet are very thick with depressed hinge lines. The young are not as thick at the edges as are the adults and more nearly resemble the common lower Permian *P. humerosus*, but differ in being centrally rotund. All known Wolfcamp *Paraparchites* have depressed hinges in contrast to the flattened hinge areas of many Leonard species.

Bone Spring formation.—The absence of *Paraparchites* from the thirty species of silicified ostracodes of Leonard age collected by Knight and Kriz from the lower part of the Bone Spring formation in Hudspeth County, north portal of Apache Canyon, Sierra Diablo, Texas, is notable. Like the fusulinids and ammonoids comparatively few Bone Spring ostracodes have been found in the Glass Mountains. Only about one-third of the species are common to the *Schwagerina crassitectoria* zone, although a few other species are closely related. This silicified fauna, however, may not be exactly equivalent to any of the *Schwagerina crassitectoria* faunas as the Bone Spring ostracodes appear to be a little more advanced and most resemble the upper fauna of the *Schwagerina crassitectoria* zone.

The Hueco and Bone Spring faunas have only about six species in common. These are all long ranging species of little stratigraphic significance.

As in the Leonard series of the Glass Mountains, the overlying Word formation, and the Kazanian series of the U.S.S.R., many of the Bone Spring ostracodes are species of *Bairdia* and representatives of the Kirkbyidae. Of the latter only 4 species out of 9, including the ever-present *Roundyella simplicissimus*, are found also in the *Schwagerina crassitectoria* zone. Several species of *Bairdia* are closely related, and two occur in both areas. Also present in both faunas is a species near *Glyptopleura emarginata*, found at depths of 1367 to 1375 feet in the Transcontinental Blackstone-Slaughter well No. 1 near the base of the Leonard (Delo, 1930).

The Bone Spring and Lueders faunas are related. Three-noded species of *Knightina* occur in both, but the Bone Spring form is larger and appears to be more advanced, with higher nodes, an extra ridge, and, on adults, short marginal spines. The Lueders formation and the *Schwagerina crassitectoria* zone also contain a *Bairdia* very close to a Bone Spring species but slightly smaller and less rotund.

The two most common Leonard markers, the large cylindrical *Darwinula*? and *Bairdia* aff. *B. beedei* are absent from the Bone Spring. Some short rather poorly preserved specimens present in the latter formation appear to be true *B. beedei* of the lower Permian.

A peculiar species in the Bone Spring fauna closely related to *Knoxina* has spines outlining not only the free margins but also the dorsal ridges. A little shortening of its hinge would cause this species to resemble certain lower Cretaceous species of *Cythereis*, but this resemblance is probably not significant as the relative sizes of the two valves are reversed.

The Bone Spring formation also carries *Cavellina ellipticalis*, *Bairdia permiana* and a small *Bythocypris*?, all common to the lower Word formation, as well as a *Kirkbya* related to *K. wordensis*. The possible forerunner of *Bairdia wordensis* has partially developed loculous structures on the inner ventral margin such as those on *B. biloculata* of the European Cretaceous, so well illustrated by Van Veen (1934, p. 20, pl. 7, figs. 1–24).

Deep wells.—The west Texas ostracodes described by Delo (1930) from deep wells in Irion, Pecos and Schleicher Counties are probably of Permian age. Those from the Transcontinental Blackstone Slaughter No. 1, Pecos County, are of Leonard age accord-

ing to Bradfield. The distinctive *Hollinella herrickiana* from a depth of 1382 feet in the Kingwood Suggs No. 1, Irion County, indicates strata of Leonard age as this species was originally described by Girty from the Yeso formation.

MIDDLE PERMIAN

West Texas.—Few ostracodes have been found above the Leonard series. Girty described several from the Delaware Mountain formation (1910, pp. 55–58) and Hamilton (1942) described a fauna of 13 silicified species representing 8 genera of 5 families from the basal part of the Word series in the Glass Mountains. The Bairdiidae and Kirkbyidae are dominant. One of the most common and striking of the five species of *Bairdia* is the ornamented *B. wordensis*, crested dorsally with 4 or 5 spines. The Kirkbyidae is represented by modifications of the lower Permian *Kirkbya wymani* and *Kellettina robusta*. Half of these Word species are found also in the Leonard series or differ only slightly from Leonard species. Among species common to the two series are *Cavellina ellipticalis*, a species of *Bythocypris?* and *Alveus depressus*, the genus *Alveus* not being known below the Leonard. Two species of *Healdia* of Pennsylvanian appearance and the extremely short hinged and dorsally flattened *Paraparchites marathonensis* complete the Word fauna.

Europe.—European strata of similar age have yielded many ostracodes, a number of which are common to the upper Magnesian limestone of England and the Zechstein series of Germany and the U.S.S.R. As in the Word formation, *Bairdia* is abundant and commonly represented by very elongate or posteriorly tapering forms. Many distinctively ornamented species of the Kirkbyidae are also present.

After a preliminary study of the Kazanian ostracodes of the U.S.S.R., Cherdyntsev (1937) concluded that many species, particularly of *Bairdia* and the Kirkbyidae, are widely distributed and have index value. Most easily recognized of the common species is an *Amphissites* characterized by a central node and horizontal bar, and *Knightina?* aff. *K. schrenki*, both probably younger than any known from the American Permian. The latter appears to be related to a Leonard species which in turn may be a more highly noded descendent of *Knightina minuta*, abundant in the upper Wolfcamp series.

Ostracodes from the Sosio beds of Sicily are almost all referred to the Cypridinidae (Gemmellaro, 1892). This Ordovician to recent family is common in the Pennsylvanian and Permian of Europe, but it is rare in the Pennsylvanian of the United States and is unknown in our Permian.

PERMIAN AND MESOZOIC FAUNAS

Permian ostracode assemblages are very different from the Mesozoic and these faunas have few if any species and only a small number of genera in common. Early in the Permian *Cornigella*, *Silenites*, *Carbonita* and *Pseudoparaparchites* disappeared, and by the end of the period *Hollinella*, *Paraparchites*, *Healdia*, *Acratia*, *Glyptopleura*, *Microcheilenella*, *Kirkbya*, *Knightina*, *Amphissites* and *Kellettina* likewise became extinct, thus closing the history of such predominant Paleozoic families as the Hollinidae, the Leperditidae, the Healdiaidae, the Glyptopleuridae, and the very prolific and hardy Kirkbyidae. The general extinction of some of these families, however, may be only apparent and representatives may be found in the little known Triassic and Jurassic faunas, or as quite altered Cretaceous genera. For example the disappearance of ridges and spines on Middle Permian *Healdia* might give rise to simple unornamented Mesozoic forms not easily recognized as relatives, and the flattening and extreme shortening of the hinge area of *Paraparchites* in the Leonard, and particularly in the Word, suggest that there might be unrecognized post-Paleozoic descendants with strongly curved dorsums, the transition having taken place in unknown Middle or Upper Permian members of this genus. The large Paleozoic family Kloedenellidae, which was formerly thought not to have survived the Permian, is now known to be represented by *Metacypris*, probably descended from Permian *Knoxina*, *Geisina*, or *Sansabella*. *Metacypris* is abundant in the fresh or brackish water faunas of the Jurassic and early Cretaceous and is found in the tidal rivers of England. The occurrence of the very distinctive Devonian genus *Phanas-*

symetrica in the European Cretaceous reported by Van Veen (1936, pp. 47–48, pl. 10, figs. 16–22, 23–30) illustrates a no less surprising extension of range.

The Cypridae, Bairdiidae and Cytherellidae evidently withstood the changes that took place at the end of the Paleozoic era, and *Bythocypris*, *Macrocypris* and *Bairdia* have persisted to the present time with little change. The common genus *Cytherella* is differentiated only by internal modifications from the abundant *Cavellina* of the Paleozoic, and Cretaceous *Cytherelloidea* resembles the common middle Pennsylvanian *Sulcella* with added ridges.

The Cytheridae is probably the predominant family of the Cretaceous. Its origin is not known but the widely differing genera suggest that it may be polyphyletic. One of its few known Paleozoic forerunners is *Basslerella* whose faint hinge teeth forecast the crenulated bar of the Cretaceous genus *Cytheridea*. *Monoceratina*, known from the Devonian to the Tertiary, has been variously referred to Paleozoic families and the Cytheridae but it is probably more closely allied to Paleozoic than to later ostracodes. A form (now being studied) discovered by the late Dr. Arthur Wedel at several localities in the Morrison group may be a forerunner of Cretaceous *Cythereis*. This undescribed genus is very closely related to *Kirkbyella* (not a member of the Kirkbyidae) but it also resembles some of the long-hinged lower Cretaceous species of *Cythereis* in shape, ornamentation and hinge structure. *Kirkbyella*, known from the Devonian to the Pennsylvanian, however, has not yet been found in Permian strata.

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JOURNAL OF PALEONTOLOGY, VOL. 17, NO. 6, P. 629, NOVEMBER, 1943

PALEONTOLOGICAL NOTES

BAIRDIA CLORENSIS COOPER, NEW NAME FOR B. SINUOSA, COOPER, 1941

CHALMER L. COOPER
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During recent work on Carboniferous ostracodes it was discovered that *B. sinuosa* Cooper (1941) is a homonym of *B. sinuosa* Morey (1936). The name *B. clorensis* is proposed for the Chester species.

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NAME REVISIONS OF SOME TERTIARY OSTRACODES[1]

L. W. LEROY

Cytheropteron minutum LeRoy (p. 361) is a homonym of *C. minutum* Sutton and Williams (Journ. Paleontology, vol. 13, p. 573, 1939) and the new name *Cytheropteron pacificum* LeRoy is proposed to replace it. The following generic changes are also recommended. M. B. Stephenson has suggested that the name *Cytheridea beaconensis* LeRoy (p. 359) be changed to *Anomocytheridea beaconensis* (LeRoy) and *Pyricythereis simiensis* LeRoy (p. 368) to *Cythereis simiensis* (LeRoy).

[1] Jour. Paleontology, vol. 17, no. 4, 1943.

ERRATA

p. 177, col. 1, line 2, delete "in".
p. 178, col. 2, line 7, for "on" read "of".
p. 179, col. 2, line 4 from last, for "lower" read "upper".
Plate expl., last line, for "x 4" read "X 3".

JOURNAL OF PALEONTOLOGY, VOL. 17, NO. 6, PP. 630–636, 2 FIGURES, NOVEMBER, 1943

REVIEW

LATE PALEOZOIC PELECYPODS: PECTINACEA, by Norman D. Newell, Kansas Geol. Survey, vol. 10, pt. 1, pp. 1–123, 20 pls., 42 text figs., 2 tables, 93 bibliographic references, "1937," July 28, 1938, for plates. Preface by Raymond C. Moore.

LATE PALEOZOIC PELECYPODS: MYTILACEA, by Norman D. Newell, Kansas Geol., Survey, vol. 10, pt. 2, pp. 1–115, 15 pls., 22 text figs., 5 tables, 85 bibliographic references, October, 1942. Preface by Raymond C. Moore.

Introduction.—So few thorough paleobiologic studies of the invertebrates have appeared in print that it is an exceptional honor to be permitted to publish a condensed summary of some of the features of Newell's two monographs in which careful attention to details has not beclouded the more important biologic and geologic aspects of the studies. The tremendous amount of labor devoted to the acquisition of basic data, the broad scope of the research, and proper taxonomic procedure are among the reasons for appreciating the training and superior ability of the author. The marked improvement of the second monograph over the first demonstrates his progress in paleobiologic and biostratigraphic investigations. To induce a large audience to share in an appreciation of Newell's notable contribution is the purpose of this review.

Treatment in both reports.—Both monographs have the same general plan of treatment: Summary of results, collections studied, distribution of species, shell morphology with an excellent glossary of shell terms, systematic paleontology, terminal bibliography, status of some foreign species, and plates. The description of species follows this arrangement: Descriptive matter, comparison, material (including statement of types or type), and occurrence. Many new species are described in each report. Both reports are based upon an examination of abundant specimens. Indeed, it is safe to say that Newell assembled for study more specimens of these kinds of Paleozoic pelecypods than has any previous worker.

The two monographs are printed in double columns, chiefly in legible 10-point type, on paper measuring 8×10 inches. The plates are half-tones, 133 screen, printed on superfinish paper.

Stratigraphic occurrence of material.—The larger stratigraphic divisions adopted in the second monograph are shown in the accompanying Table I. From the two reports the reviewer has compiled the lowest and highest occurrences of Pennsylvanian and Permian specimens from North America. This compilation of carefully differentiated genera and subgenera is arranged in stratigraphic order for the benefit of the biostratigrapher. Those concerned with the Permian-Pennsylvanian problem may be interested in analyzing this table; perhaps they will conclude that the data presented indicate that no profound change in these marine organisms took place during this part of Paleozoic time. Confidence in such a conclusion is inspired by the following quotation from page 36 of the 1942 monograph:

> In these days paleontologists have a distaste for long-ranging genera and species, and many follow the practice of evaluating observed characters of shells in terms of their stratigraphic position, and in many instances very similar fossils have been given different names to better emphasize unlike stratigraphic occurrences. Where the stratigraphic measure is employed, however, in differentiating fossil units, the classification should by all means be based on proven shell characters and not simply on suspected distinction.

Newell gives many data on the shell characters of the species. The distinctions are biologic, not stratigraphic. The second monograph contains graphs and scattergrams as aids in differentiating species. One feels, therefore, that he can place some reliance on the ranges of the genera and subgenera given in Table I. Of course, the monographs have clarified the taxonomic units and biostratigraphers may extend the terminal stratigraphic ranges because they will be "pectinoid and myaline minded." For instance, Newell and Kummel (1)[1] have recorded *Myalina* in the Triassic Dinwoody formation of Montana, Wyoming, and Idaho.

[1] Footnotes and references are given at the end of this review.

Habits and habitats.—A careful paleontologist such as Newell asks two questions concerning the fossils he studies: What is the chronologic value of this specimen? and What is its value as an environment indicator? Newell answers both queries. Considering available evidence, he concludes that probably many of the Paleozoic Mytilacea lived under conditions similar to those favored by modern *Mytilus* and *Volsella* that is, in the shallow, turbid waters of the shore zone, tolerating an unusually great amount of variation in the salinity of the water.

TABLE I.—PECTINACEAN AND MYTILACEAN PELECYPOD GENERA AND SUBGENERA FROM NORTH AMERICAN LATE PALEOZOIC FORMATIONS. REPRESENTATIVE SPECIMENS OF EACH GENUS AND SUBGENUS HAVE BEEN STUDIED BY NORMAN D. NEWELL

	Pennsylvanian					Permian			
	Morrowan	Lampasan	Desmoinesian	Missourian	Virgillian	Wolfcampian	Leonardian	Guadalupian	Ochoan
Acanthopecten†				×				×	
Annuliconcha†				×	×			×	
Aviculopecten†	×	×	×	×	×	×	×	×	
Camptonectes?								×	
Girtypecten								×	
Myalina†*		×	×	×	×	×		×	
Myalina (Myalinella)			×	×	×	×	×	×	
Pernopecten†		×		×	×			×	
Pseudomonotis			×	×	×	×	×		
Clavicosta				×		×			
Limipecten†			×		×	?			
Myalina (Orthomyalina)			×	×	×	×			
Promytilus				×	×	×			
Septimyalina	×	×	×	×	×	×			
Streblochondria†				×	×	×			
Dunbarella†			×		×				
Euchondria†	×		×	×	×				
Pterinopectinella†				×	×				
Volsellina		×	×	×	×				
Fasciculiconcha			×	×					
Lithophaga*				×					
Selenimyalina			×	×					
Streblopteria†			×	×					
Posidonia†*		×							
Naiadites†?*?	×	×							

† Indicates genera represented in pre-Pennsylvania strata.
* Indicates genera occurring in post-Permian rocks.

Shell microstructure.—Newell has paid more than passing attention to the microstructure of the shells. Having summarized the literature on the shell structure of pelecypods nearly nine years ago (2), the reviewer was naturally pleased to find a modern American worker who has contributed first-hand observations to this neglected aspect of conchology. Newell found that in Paleozoic pectinoids consistent differences in shell structure exist between tribes that are also separable by form and ornamentation. Pennsylvanian specimens of the Mytilidae had an original shell structure like that of *Mytilus edulis*. Critical differences in shell structure between the Mytilidae and Myalinidae commonly can be distinguished with a hand lens or low-power microscope. Unlike the prisms in the Mytilidae, those of the Myalinidae are perpendicular to the shell surface instead of tangential to it.

Ligament.—The author gives considerable attention in each monograph to the ligament

area for the reason that the ligament has been neglected by most students of pelecypods. Its usefulness in classification has not been appreciated.

In the first report, he recognizes four principal kinds of ligament areas, each of which was developed at various times in distantly related or unrelated groups. The first kind is found in such Devonian forms as *Pterinopecten* and *Lyriopecten* and is identical with that of the modern "*Arca*,"—*Anadara* (3), (4). The second is found in *Limipecten*, *Aviculopecten*, *Pinctada* ("*Meleagrina*"), and many others. The third is seen in *Perna* and *Crenipecten*. The fourth kind of ligament is that characteristic of *Pecten*.

In the second monograph (pp. 23–24) Newell points out that the ligament commonly consists of two unlike kinds of elastic conchiolin. One is impregnated with spicules of aragonite. This is the fibrous ligament; it is elastic only to compressional stresses. The other kind is the lamellar ligament and contains no calcareous material; it is highly elastic to both compressional and tensional stresses. The latter ligament functions chiefly as a tensional organ because it lies above the hinge axis. The type of C-spring ligament found in *Mytilus* is widely known as parivincular. The complex ligament of some arcids and myalines Newell calls *duplivincular*. These are among the many instructive statements which the reader may glean from the publications.

Musculature.—The most striking distinction in musculature between the Paleozoic pectinoids and the modern representatives of the Pteriidae and Pectinidae lies in modifications of the pedal muscles and pallial muscle system. On pages 21–24 of the earlier monograph, Newell discusses and illustrates the musculature of modern and Paleozoic Pectinidae, Pteriidae, and Paleozoic pectinoids. On pages 29–31 of the later report he describes and figures the musculature of *Volsella "modiola"* (5), *Selenimyalina melini-formis*, *S. perattenuata*, *Mytilus edulis*, *Myalina goldfussiana*, *Naiadites carbonarius*, and *Orthomyalina slocomi*. He concludes that the musculature of the Paleozoic myalines was practically identical with that of modern Mytilidae and unlike that of other dysodonts. Therefore, he was led to conclude that the myalines are properly allocated to the Mytilacea instead of to the Pteriacea.

Taxonomic results, pectinoids.—Musculature, hinge, ornamentation, and shell microstructure were employed in proposing a classification which has been greatly condensed for this review.

Family Pterinopectinidae Newell (Silurian to Pennsylvanian, inclusive) including these genera: *Pterinopecten* Hall, *Rhombopteria* Jackson, *Palaeopecten* Williams, *Posidonia* Bronn, *Lyriopecten* Hall, *Vertumnia* Hall, *Pseudaviculopecten* Newell, *Dunbarella* Newell, and *Pterinopectinella* Newell.

Family Aviculopectinidae Etheridge, Jr., emend. Newell. This is divided into the subfamily Aviculopectininae Meek and Hayden emend. Newell, subfamily Streblochondriinae Newell, and the subfamily Pseudomonotinae Newell.

The family Euchondriidae Newell proposes for the genus *Euchondria* Meek, Devonian through Pennsylvanian in range. The family Amussiidae Ridewood comprises the modern genus *Amusium* and the Carboniferous-Permian genus *Pernopecten* Winchell.

Two general kinds of ligamental structure in the Paleozoic pectinoid shells separate the older Paleozoic constellations of species from the younger Paleozoic ones. The older Paleozoic shells—the Pterinopectinidae—have ligamental areas similar to those of the modern Arcidae. Beginning in Mississippian time, however, another kind of ligament, similar to that in the modern Pteriidae, began to supplant the pterinopectinid structure. In this later family, the Aviculopectinidae, there is a well-defined, flat, smooth, external ligament area in each valve, with an oblique, subcentral resilifer beneath each beak.

The family Euchondriidae comprises aviculopectinoids in which, in addition to a relatively large, oblique, median resilifer, there is a series of narrow quadrate and transverse resilifers in front of and behind the beaks, extending along the flat and diverging ligament areas, as do those in *Aviculopecten*. The outer ostracum of the right valve in the type genus of the family Euchondriidae is prismatic, that of the left is structureless.

The probable relationships and ranges in

time of the Paleozoic Pectinacea are shown in the accompaning figure 1. This figure is a consolidation of Newell's figures 14 and 17, redrawn for presentation here.

enies of the more specialized species in each phyletic line. The more conspicuous evolutionary trends in form in the family Myalinidae include changes in shell obliquity and

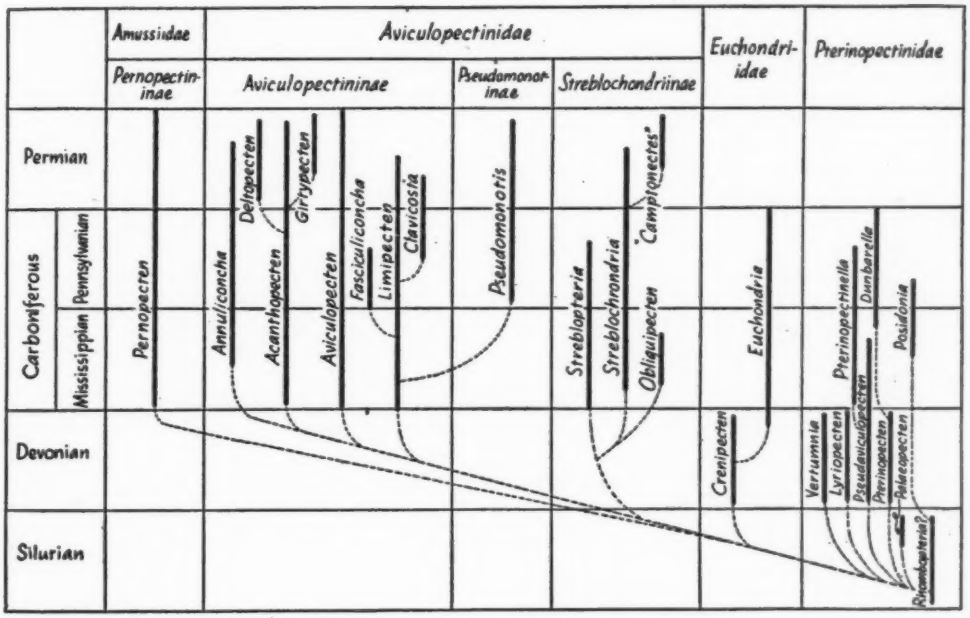

FIG. 1.—Possible relationships of Paleozoic Pectinacea, according to Newell (1938).

Taxonomic results, mytilaceans.—The author adopts the following classification of the subfamily Mytilacea:

Family Mytilidae Fleming, with the genera *Mytilus* Linnaeus, *Volsella* Scopoli, *Promytilus* Newell, *Volsellina* Newell, *Lithophaga* Bolten, and *Lithodomina* Waagen (6).

Family Myalinidae Frech, emend. Newell, including the genera *Myalina* DeKoninck (and the subgenera *Myalina, s.s., Orthomyalina* Newell, and *Myalinella* Newell), *Selenimyalina* Newell, *Septimyalina* Newell, *Naiadites* Dawson, *Liebea* Waagen, *Atomodesma* Beyrich, *Maitaia* Marwick, and *Aphanaia* De Koninck.

The Myalinidae are more highly specialized than the probable ancestral stock, the Mytilidae. The myalines include some of the best guide fossils among the pelecypods. The progressive modifications in shell shape through the stratigraphic sequence are striking and are recapitulated in the ontog-

the development of a rear wing. This is also true in the Mytilidae, Ambonychiidae, Pteriidae, and other unrelated pelecypod families. Such parallelism in development recalls homoeomorphic (7) trends in the ammonite suture, in the shell form of certain brachiopod stocks, graptolites, corals, and other invertebrates.

An example of palingenesis is given in figure 2, which is a photographic reproduction, slightly reduced in size, of Newell's figure 12. The outlines of a succession of specimens of species are shown in stratigraphic succession. These outlines may be correlated with ontogenetic stages of one of the most highly developed species, *Myalina* (*Myalina*) *copei* Whitfield. The cessation of expansion of the rear auricle and general slackening of peripheral increase are interpreted by Newell as gerontic characters. The gerontic stage of *M. copei* shows that old age is not reached simultaneously in all

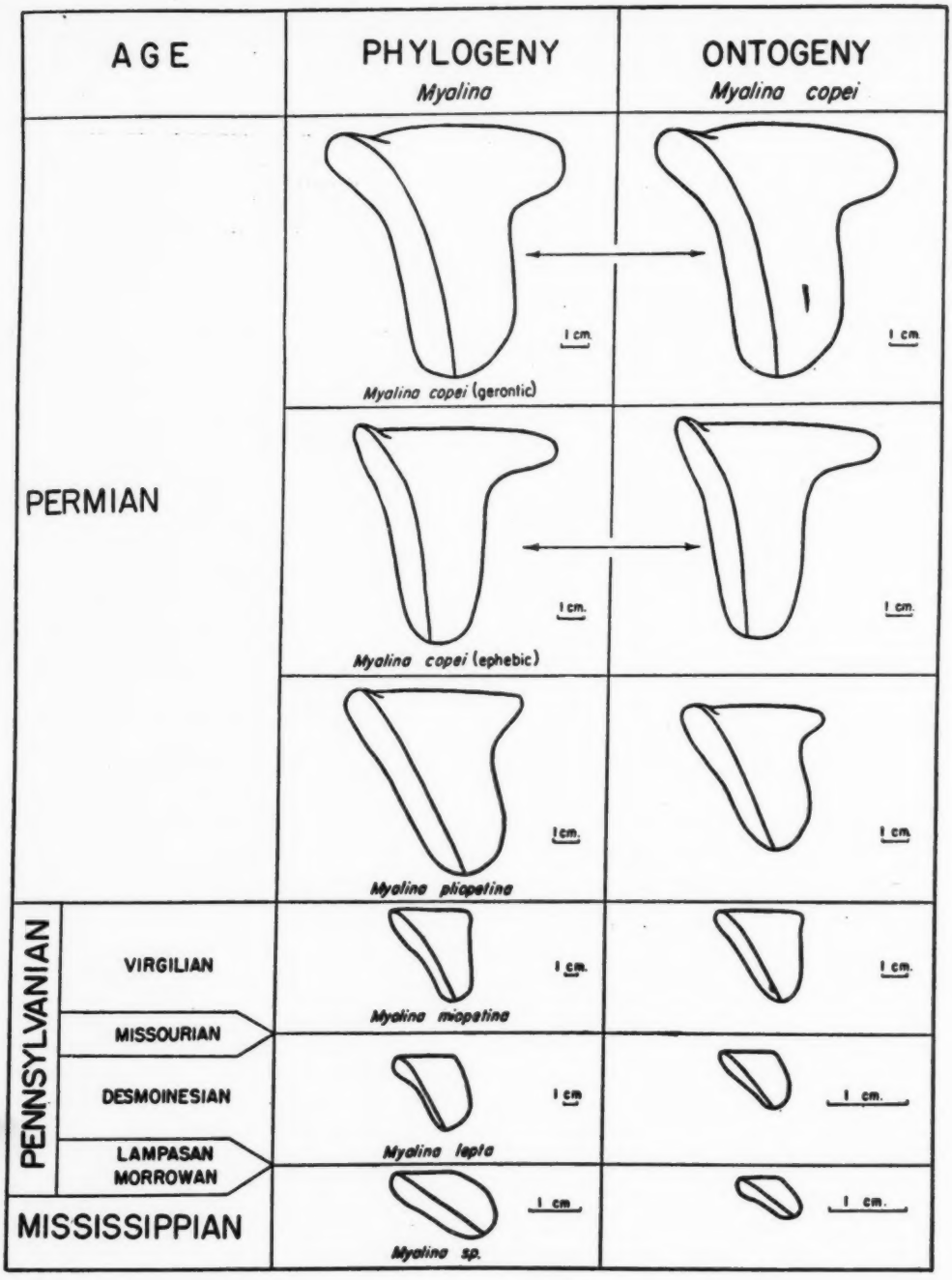

FIG. 2.—Example of palingenesis in *Myalina*, from Newell (1942).

biocharacters, since the forward curvature of the umbonal ridge, responsible for decreasing obliquity, seems to be unchecked, whereas the rear auricle no longer expands.

Students of the pelecypods have long waited for the statement of the difference between *Naiadites* and *Myalina* made by Newell (1942, pp. 71–72). In *Myalina* the beaks are terminal; in *Naiadites*, the beaks are not terminal. This is one way to distinguish the present-day *Mytilus* from *Volsella*.

Discussion.—During the past decade few comprehensive reports on Paleozoic pelecypods have been published. Among the monographs are those by Isberg (8) and Maillieux (9). Some revisions are necessary as a result of Newell's exhaustive investigations. For example, Maillieux (p. 104) proposed *Demanetia* as a subgenus of *Myalina*. This subgenus will have to be removed not only from the genus but even from the family Myalinidae (1942, p. 44), because Newell excludes from the family those genera whose representatives are radially ornamented.

Taxonomists will be impressed by the pains taken by Newell to determine the biological constitution of the genera and subgenera. The holotype of the European *Myalina goldfussiana* DeKoninck, the genolectotype of *Myalina*, was studied and the conclusion reached that the American species are properly assigned to that genus. Similarly, specimens of the genolectotype of *Naiadites*, *N. carbonarius* Dawson from the Upper Carboniferous of Nova Scotia, are reported upon in the text (1942, pp. 70–71). Notwithstanding the author's care, all is not clear sailing for the reader and no identification key aids him. *Promytilus* offers an example of the difficulty one may have in comprehending the morphologic limits of a genus. Newell (1942, pp. 36–37) proposes this new Paleozoic genus, typified by *Promytilus annosus* Newell, for a bivalve which is structurally intermediate between *Volsella* and *Mytilus*. Conchologists may not be sure which shell characters separate the genera, particularly when noting the marked similarity between the figured Paleozoic specimens of *Promytilus annosus* Newell and the Recent species *Volsella tulipa* (Lamarck). *Volsella modiolus*, one of the many living species of the genus, is itself variable, according to Soot-Ryen (10) and Lamy (11). It would be instructive to learn how the hinge of *Promytilus* compares with the hinge of *Mytilus*, as figured by Lamy (12), fig. 1, p. 73), at the same ontogenetic stage.

So far as the reviewer has ascertained, the earliest attempt in North America to set up a time-stratigraphic classification of late Paleozoic rocks, utilizing chiefly paleontologic criteria, is that by Beede and Rogers (13). They were well aware (p. 348) that the boundary between the Pennsylvanian and Permian was not stable, but their stratal classification was independent of any dispute concerning this line. It is instructive, even amusing, to follow (14) the recent published changes of this boundary and the shifting of the division lines within the systems. Research might show more similarity than difference between the old classification and the new one adopted by Newell. "Series III" of Beede and Rogers, slightly modified, corresponds to the Virgilian as used by Newell (1942), p. 15). "Series II" may roughly coincide with the Missourian, and "Series I" with the Desmoinesian. So detailed have been the stratigraphic studies in Kansas and adjacent states in the past three decades, and so thorough are some of the later paleobiologic researches in that region, that the time seems to be ripe for a biostratigrapher to set up a proper time-stratigraphic classification (15) of the North American late Paleozoic rocks.

In conclusion, Newell's study of the Mytilacea so admirably deals with these pelecypods that his monograph must take its place along side of the noteworthy recent contributions to molluscan paleontology by Henry Hurd Swinnerton (16), Weir and Leitch (17), Leitch (18), and Trueman (19).

In this appraisal of the reports by Newell, one statement of Swinnerton (16, 1940, p. lxxvii) is especially appropriate:

> The only reliable starting-point for further progress in palaeontological thought is that provided by the very careful and precise work that has been, and is being done by systematists.

And thus it is that Newell will induce progress in paleontology.

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2. SCHENCK, H. G., 1934, Literature on the shell structure of pelecypods: Mus. royal histoire nat. Belgique Bull., t. 10, no. 34, pp. 1–20.
3. REINHART, P. W., 1935, Classification of the pelecypod family Arcidae: Mus. royal histoire nat. Belgique Bull. t. 11, no. 13, pp. 1–68.
4. SCHENCK, H. G. and REINHART, P. W., 1938, Oligocene pelecypods of the genus *Anadara:* Mus. royal histoire nat. Belgique Mém., sér. 2, fasc. 14, pp. 1–74, 6 pls., 12 figs.
5. The genus *Volsella* is "*Modiolus*" to many workers. A. M. Keen, who kindly read a draft of this review, points out that the species name of the genotype should be written *Volsella modiolus*, "*modiolus*" being a Latin noun in apposition, not an adjective. See International Rules of Zoological Nomenclature, Article 14 (b).
6. The reader will understand that Newell did not attempt to list all of the bivalves which belong in the family Mytilidae. For several others that belong there, consult Thiele, J., 1934, Handbuch der Systematischen Weichtierkunde, 3 Teil, pp. 797–801.
7. Writers are not always consistent in the spelling of the word "homoeomorphic," using sometimes "homeomorphic." The term "homoeomorph" was coined by Buckman; Eimer proposed "homoeogenesis." Hyatt used the expression "morphological equivalent" for homoeomorph. For a concise discussion, consult A. W. Grabau, Principles of Stratigraphy, Second Edition, pp. 976–979, 1924.
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